Food and Agriculture Organization of the United Nations

*for a world without hunger*

HOW TO FEED THE WORLD 2050

EXPERT MEETING

24-26 June 2009 FAO headquarters, Rome



## Proceedings of the Expert Meeting on How to Feed the World in 2050

Technical papers were commissioned from experts and are published as submitted by the authors.

## Proceedings of the Expert Meeting on How to Feed the World in 2050

Abbreviations used in the expert papers on How to Feed the World in 2050

| | |
|---|---|
| **$** | US dollars |
| **AoA** | Agreement on Agriculture (World Trade Organization) |
| **ACS** | agricultural capital stock |
| **ACP** | African, Caribbean and Pacific Group of States |
| **AKST** | agricultural knowledge, science and technology |
| **ASARECA** | Association for Strengthening Agriculture in Eastern and Central Africa |
| **AY** | attainable yield |
| **CAADP** | Comprehensive Africa Agriculture Development Programme |
| **CBOT** | Chicago Board of Trade |
| **CDD** | community-driven development |
| **CFF** | compensatory financing facility |
| **CGE** | computable general equilibrium |
| **CGIAR** | Consultative Group on International Agricultural Research |
| **DEA** | data envelopment analysis |
| **ENVISAGE** | Environmental Impact and Sustainability Applied General Equilibrium Model |
| **EU** | European Union |
| **FAO** | Food and Agriculture Organization |
| **FAOSTAT** | FAO statistical database |
| **FAPRI** | Food and Agriculture Policy Research Institute |
| **FBS** | food balance sheets |
| **FDI** | foreign direct investment |
| **FIFF** | food import financing facility |
| **FTE** | full-time equivalent |
| **FY** | farm yield |
| **GAEZ** | global agro-ecological zone |
| **GATT** | General Agreement on Tariffs and Trade |
| **GCM** | general circulation model |
| **GDP** | gross domestic product |
| **GHG** | greenhouse gas |
| **GIDD** | Global Income Distribution Dynamics [model] |
| **GIEWS** | FAO Global Information and Early Warning System |
| **GM** | genetically modified |
| **GMC** | global middle class |
| **GMO** | genetically modified organism |
| **GSE** | gross subsidy equivalent |
| **GTAP** | Global Trade Analysis Project |
| **IAM** | integrated assessment model |
| **ICOR** | Incremental Capital Output Ratio |
| **ICP** | International Comparison Project |
| **ICT** | information and communication technologies |
| **IFAD** | International Fund for Agricultural Development |
| **IFPRI** | International Food Policy Research Institute |
| **IMF** | International Monetary Fund |
| **IMPACT** | International Model for Policy Analysis of Agricultural Commodities and Trade |
| **IP** | intellectual property |
| **IPCC** | Inter-governmental Panel on Climate Change |
| **IRRI** | International Rice Research Institute |
| **IT** | information technology |
| **LAC** | Latin America and the Caribbean |
| **LDCs** | least developed countries |
| **LIFDCs** | low income food deficit countries |
| **MARS** | marker-assisted recurrent selection |
| **MAS** | marker-assisted selection |
| **MDERs** | minimum dietary energy requirements |
| **MDG** | Millennium Development Goals |
| **MIC** | middle income countries |
| **MPS** | market price support |
| **MV** | modern varieties |
| **NGO** | non-governmental organization |
| **NRA** | nominal rate of assistance |
| **ODA** | official development assistance |
| **OECD** | Organisation for Economic Co-operation and Development |
| **OFID** | OPEC Fund for International Development |
| **OPEC** | Organization of Petroleum-Exporting Countries |
| **PIM** | perpetual inventory method |
| **PPP** | purchasing power parity |
| **PSE** | producer subsidy equivalent |
| **PY** | potential yield |
| **PYw** | water-limited potential yield |
| **R&D** | research and development |
| **SAP** | standard accounting procedure |
| **SPS** | Sanitary and Phytosanitary Agreement (World Trade Organization) |
| **TBT** | Technical Barriers to Trade |
| **TFP** | total factor productivity |
| **TV** | traditional varieties |
| **UN** | United Nations |
| **UNCTAD** | United Nations Conference on Trade & Development |
| **WDI** | World Development Indicators |
| **WDR** | World Development Report |
| **WFS** | World Food Summit |
| **WTO** | World Trade Organization |

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## Proceedings of the Expert Meeting on How to Feed the World in 2050

*These papers were commissioned by FAO to provide technical background material for the High-Level Expert Forum on "How to Feed to World in 2050" to be held at FAO, Rome, 12-13 October 2009. Please see the meeting report for expert comments on these papers as well as additional presentations made at the June 2009 Expert Meeting.**

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**The views expressed in these papers are those of the author(s) and do not necessarily reflect the views of the Food and Agriculture Organization of the United Nations.*

# MACROECONOMIC ENVIRONMENT, COMMODITY MARKETS: A LONGER TERM OUTLOOK

**Dominique van der Mensbrugghe, Israel Osorio-Rodarte, Andrew Burns and John Baffes***

## ABSTRACT

The recent commodity boom was the longest and broadest of the post-World War II period. Although most prices have declined sharply since their mid-2008 peak, they are still considerably higher than 2003, the beginning of the boom. Apart from strong and sustained economic growth, the recent boom was fueled by numerous other factors including low past investment in extractive commodities, weak dollar, fiscal expansion in many countries, and, perhaps, investment fund activity. On the other hand, the diversion of some food commodities to the production of biofuels, adverse weather conditions, global stock declines to historical lows and government policies, including export bans and prohibitive taxes, accelerated the price increases that eventually led to the 2008 rally. This paper concludes that the increased link between energy and non-energy commodity prices, strong demand by developing countries - when the current economic downturn reverses course - and changing weather patterns will be the dominant forces that are likely to shape developments in commodity markets.

## I. INTRODUCTION

By most accounts, the recent commodity boom was the longest and broadest (in terms of commodities involved) of the post-World War II period (World Bank 2009). Between 2003 and 2008, nominal energy and metal prices increased by 230 percent, food and precious metals doubled, while fertilizer prices increased four-fold. Although most prices have declined sharply since their mid-2008 peak, they are still considerably higher than their 2003 levels.

Apart from broad and sustained economic growth, the boom was fueled by a host of other factors both macro and long-term as well as sector-specific and short-term. These include: low past investment in extractive commodities, a reflection of a prolonged period of declining prices due excess capacity left after the collapse of the Soviet Union and weak demand after the 1997 East Asian (and other countries) financial crisis; weak dollar (the currency of choice in most international commodity transactions); fiscal expansion and loose monetary policies in many countries; investment fund activity by financial institutions which chose to include commodities in their portfolios. On the other hand, the diversion of some food commodities to the production of biofuels (notably maize in the US and edible oils in Europe), adverse weather conditions (e.g. three droughts in Australia during 2001-2007), global stock declines of several agricultural commodities to historical lows, and government policies such as export bans and prohibitive taxes further contributed to the 2008 rally. Geopolitical concerns played a key role as well, especially in energy markets.

In some sense, the above factors created the "perfect storm" which reached its zenith in July 2008 when crude oil prices averaged $133 per barrel (up 94 percent from a year earlier) and rice prices doubled within just five months (from $375 per ton in January to $757 per ton in June 2008). Not surprisingly, the weakening and/or reversal of these factors coupled with the financial crisis that erupted in September 2008 and the subsequent global economic downturn, induced sharp price declines across most commodity sectors.

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The recent boom, and especially the 2008 rally, has generated renewed interest for the determinants of commodity prices, including the role of commodity-specific factors, macroeconomic fundamentals, as well as questions on whether a permanent shift in price trends has taken place. On the other hand, food availability and food security concerns generated calls for coordinated policy actions at national (and perhaps international) level, reminiscent to actions taken in earlier booms. With that context in mind, this paper identifies and analyzes the dominant forces that are likely to shape long term developments in commodity markets. Such forces include (but they are not limited to) the increased interdependence between energy and non-energy markets, the growth prospects especially in developing countries where most consumption growth is expected to take place, the effect of climate change in the production and trade of commodities, and, at the outset, what all this implies for poverty.

The rest of the paper begins with a brief discussion recent price trends, including the causes of the recent commodity price boom. This is followed by an analysis of the energy/non-energy price link. The subsequent three sections deal with the issues of the growth prospects, global warming, and their implication on poverty. The last section concludes with a summary and a policy discussion.

## II. THE NATURE OF THE RECENT COMMODITY BOOM

The recent commodity boom shares a number of similarities with earlier booms but it also has some differences. It involved almost all commodities (see figures 2.1 and 2.2) as opposed to earlier booms which involved only agriculture (Korean war) or agriculture and energy (1970s energy crisis). It was not associated with high inflation as opposed to the 1970s which was associated with inflationary pressures. On the other hand, all three booms took place against the backdrop of high and sustained economic growth. Furthermore, all three booms generated discussion on coordinated policy actions due to concerns over food security and energy availability issues.

The reasons behind the recent boom are numerous, and as many analysts have argued, they created a "perfect storm." On the one hand, most countries enjoyed sustained economic growth for a long period of time. During 2003-07, growth in developing countries averaged 6.9 percent, the highest 5-year average in recent history (the second highest 5-year average, 6.5 percent, took place during 1969-73). Fiscal expansion in many countries and low interest rates created an environment which favored high commodity prices. The depreciation of the US dollar played some role since it is the currency of choice for most international transactions.

On extractive sectors, especially energy commodities, underinvestment during the late 1980s and 1990s left limited room for supply response. For example, during the early 1980s, total investment expenditures by the major US multinational oil and gas companies averaged more than $130 billion annually (real 2006 terms). For the next 15 years, however, the annual average dropped to half as much (see figure 2.3). Similar reductions in investment took place in most metal sectors.

Another factor believed to have played a key in the recent boom is the decision by many index fund to include commodities in their holdings as a way to diversify their portfolios away from traditional asset classes such as equities and bonds. While the evidence on the effect of investment fund activity on commodity prices has been missed, many experts believe that such funds were the key reason behind the 2008 rally (see discussion in box 1 and figure 2.7 on different types of speculation, including investment fund activity).

The diversion of considerable quantities of some food commodities for the production of biofuels was a key factor behind the recent boom. Almost 28 percent of US maize area (corresponding to about 1.33 percent of global grain area) was diverted to ethanol production during 2008-09. While the combined maize and oilseed area corresponding to biofuel production corresponds to about 2 percent of global grain and oilseed area, the sharp increase in diversion during the recent 2-3 years came at a time when global grain stocks were at historical lows thus leaving limited room for adjustment by bringing more land into productive uses (see figure 2.6 for historical stock-to-use ratio).

When most prices began rallying during the early 2008, many governments faced increased pressure by consumers of key food commodities (especially rice) to contain domestic food price inflation. In response, they imposed various export controls, including exports bans and prohibitive export taxes. While such measures temporarily contained domestic price increases, they further exacerbated world prices increases, especially in the rice market which is very thin (less than 10 percent of global rice production is internationally traded).

In addition to the above factors, increased grain consumption by low and middle income countries (especially China and India) due to rising incomes and changing diets (from grain to meat consumption) has often been cited as key reason that fueled the boom, including the 2008 rally. Yet, as figures 2.4 and 2.5 indicate the combined grain consumption (both for human and animal use) by China and India increased only slightly after 1995, a period during which both countries enjoyed strong economic growth. More importantly, grain consumption in these two countries declined during 1995-2007 if expressed as a share of global consumption. This should not be surprising in view of the low income elasticity of grains even at low per capita incomes (see table 2.1).

## III. THE ENERGY/NON-ENERGY PRICE LINK

It has become increasingly clear that the energy price increases of the last few years will reshape not only energy markets but most other markets, including agriculture. For almost 20 years, the price of crude oil averaged about $20 per barrel (real 2000 terms). Most analysts and researchers now believe that the "new" equilibrium price of oil will be at three times as much, with proportional changes expected to take place in all other types of energy. High energy prices along with the high energy intensity of most commodities imply that developments in non-energy (especially food) markets will depend on the nature and degree of the energy/non-energy price link. The remaining of this section elaborates on this issue.

The channels through which energy prices affect other commodities are numerous. On the supply side, energy enters the aggregate production function of most primary commodities through the use of various energy-intensive inputs and, often, transportation over long distances, an equally energy demanding process. Some commodities have to go through an energy-intensive primary processing stage. Other commodities can be used to produce substitutes to crude oil (e.g. maize and sugar for ethanol production or edible oils for biodiesel production). In other cases, the main input may be a close substitute to crude oil, such as nitrogen fertilizer which is made directly from natural gas. (The various transmission channels from energy to non-energy prices have been discussed in Baffes (2007, 2009), FAO (2002), and World Bank (2009), among others.)

This section examines the energy/non-energy price link by estimating the following relationship:

$$\log(NON\_ENERGY_t) = \mu + \beta_1 \log(ENERGY_t) + \beta_2 \log(MUV_t) + \beta_3 TIME + \varepsilon_t. \qquad \textbf{(see Table 3.1)}$$

$NON\_ENERGY_t$ denotes the various non-energy US dollar-based price indices at time $t$, $ENERGY_t$ denotes the energy price index, $MUV_t$ denotes the deflator, $TIME$ is time trend, and $\varepsilon_t$ denotes the error term; $\mu$, $\beta_1$, $\beta_2$, and $\beta_3$ denote parameters to be estimated. Annual data for a number of commodity indices and prices covering the period from 1960 to 2008 are used in the analysis. Although the signs and magnitudes of the coefficients are not dictated by economic theory, $\beta_1$ and $\beta_2$ are expected to be positive because energy as well as other goods and services (as reflected by the measure of inflation) constitute key inputs to the production process of all commodities. On the other hand, $\beta_3$ is expected to be negative, at least for agricultural commodities—consistent with the long-term impact of technological progress on production costs as well as the low income elasticity of most food commodities, especially cereals.

The estimates, presented in table 3.1, indicate that energy prices and to a lesser extent inflation and technological change explain a considerable part of commodity price variability (the adjusted $R^2$ of all regressions averaged 0.85). Specifically, the parameter estimate of the non-energy index (top row of table 3.1) is 0.28, implying that a 10 percent increase in energy prices is associated with a 2.8 percent increase in non-energy commodity prices, in the long run. Three earlier studies—Gilbert (1989), Borensztein and Reinhart (1994), and Baffes (2007)—reported elasticities of 0.12, 0.11, and 0.16, respectively (table 3.2). When the sample of the current analysis is adjusted to match the samples of these studies, the pass-through coefficient becomes remarkably similar (0.13 and 0.12, and 0.18, respectively).

The transmission elasticity of the non-energy index, however, masks some variations. The highest pass-through elasticity among the sub-indices was in fertilizer, estimated at 0.55, not surprisingly since nitrogen-based fertilizers are made directly from natural gas. Note that the fertilizer and energy price increases during the recent boom were in line with the increases experienced during the first oil shock: from 1973 to 1974 phosphate rock and urea prices increased four-fold and three-fold, very similar to the crude oil price increase during that period, from $2.81 per barrel to $10.97 per barrel.

The agriculture pass-through, estimated at 0.27, reflects a wide-ranging average: beverages (0.38), food (0.27) and raw materials (0.11). Yet, the elasticity estimates of the food price index components fall within a very narrow range: cereals (0.28), edible oils (0.29), and other food (0.22). Similarly, the estimates for the key food commodities fall within a relatively narrow range, from a low of 0.25 in rice to a high of 0.36 in soybeans (Table 3.3).

Three key conclusions emerge from these results. First, most commodities respond strongly to energy prices, a response that appears to strengthen in periods of high prices as confirmed by the fact that the values of the estimated elasticities increase considerably when the recent boom is included in the analysis. The implication is that, for as long as energy prices remain elevated, not only non-energy commodity prices are expected to be high, but analyzing the respective markets requires understanding of the energy markets as well.

Second, while the transmission elasticities were broadly similar, this was not the case with the inflation coefficient the estimates of which varied considerably in terms of sign, magnitude, and level of significance. It was positive and significantly different from zero only for agriculture (and some of its sub-indices) while it was effectively zero for metals and fertilizers. All this implies that the relationship between inflation and nominal commodity prices is much more complex and, perhaps, changing over time. This may not be surprising if one considers that during 1972-80 (a period which includes both oil shocks) the MUV increased by 45 percent while during 2000-08, it increased by half as much. The nominal non-energy price index increase during these two 8-year periods was identical at 170 percent.

Third, the trend parameter estimates are spread over an even wider range compared to energy pass-through and inflation. The non-energy price index, for example, shows no trend at all. Yet, the metal price index exhibited an almost two percent positive annual trend while the agriculture index showed a one percent negative annual trend. Furthermore, the trend parameter estimates of the agriculture sub-indices vary considerably, from 0.08 for raw materials to -3.12 for beverages, a result which confirms Deaton's (1999, p. 27) observation that what commodity prices lack in trend, they make up in variability. On the other hand, the trend estimate of the food index, -0.71, significant at the 10 percent level, may add another dimension to the debate on the long-term decline of primary commodity prices, often discussed in the context of the Prebisch-Singer hypothesis (see Spraos 1980, among others).

## IV. THE MACROECONOMIC ENVIRONMENT

A number of factors will shape the macroeconomic environment and agricultural supply and demand balances over the medium term (through 2030) and the longer term (through 2050). The starting point of any such analysis is demographics. Between 1950 and 2000 the world saw a huge expansion in global population, an increase of some 3.6 billion persons, or a 250 percent rise compared with 1950 (Figure 4.1). Over the next 50 years, the expansion will slow down considerably, with, according to the UN's medium variant, an increase of 50 percent over 2000, but coming off a much higher base, this still represents a rise of 3 billion persons. The distributional implications of the population rise are also important. There will be nearly no increase in the high-income countries, but yet a 150 percent increase in the least developed countries.[1] Many of the least developed

[1] Using today's definition of least developed.

are countries that have been under significant stress to feed their growing population for both natural and man-made reasons. On the other hand high-income countries have both stagnating populations and food demand and robust agriculture. This combination could lead to increased reliance of the least developed countries on food imports, with other developing regions lying somewhere in between—some with surpluses, such as many Latin American countries and others with potentially growing deficits as some in Asia. The bottom line is that agricultural production has to increase at an average rate of 0.8 percent per annum simply to accommodate population growth and in the least developed countries it would have to grow at an average rate of 1.8 percent over the 50-year period.

The economic factors that will determine food supply and balances can be divided into two categories - demand and supply factors, and these of course will be regionally differentiated. Historically, demand has been conditioned by two factors - income growth and shifts in tastes (often derived from income growth), for example a switch from a diet largely based on grains to more reliance on meat- and dairy-based proteins. In most high-income countries, and some developing countries, the income elasticity for food is nearly 0 for many food commodities as saturation points have been reached.[2] There is nonetheless a substantial portion of the global population that would potentially demand relatively more food as incomes rise. The World Bank's most recent estimate of the incidence of poverty in developing countries was around 47 percent (at the $2/day level) in 2005, declining to around 35 percent by 2015. And the intensification of meat and dairy consumption would raise the demand for grain-based feed, in larger proportion than any relative drop in household based grain demand.

Though we regularly project income growth over the medium- and long-term horizons, one should keep in mind that these are strictly scenario-based (or what-if?) projections and not statistically-based projections as are the more standard short-term forecasts of economic growth. Our projections use a hybrid system where in the short- and medium-term we rely more on estimates of potential growth using statistical techniques, but over the longer-term we switch to a more judgmental forecast that relies on two assumptions: 1) long-term per capita growth in high-income countries will slow to 1.0-1.5 percent per annum; and 2) developing countries will converge towards the per capita incomes of the high-income countries, but at different rates.

Our baseline projection has the global economy increasing at an average rate of around 2.9 percent between 2005 and 2050 (Figure 4.2). This breaks out into 1.6 percent for high-income countries and a brisk 5.2 percent for the developing countries. One of the key consequences of this differential in growth rates is that we witness a very large shift in share of global output. In 2005, developing countries had roughly a 20 percent share in global output (at market exchange rates). By 2050, this jumps to about 55 percent. On a per capita basis the growth differential narrows as population growth is near zero in the high-income countries. At market exchange rates, there is a narrowing of the income gap, but it remains substantial. In 2005, per capita incomes were some 20 times higher in high-income countries relative to developing. This ratio drops to 6 by 2050 though varies highly across regions—with a low of 3.5 in East Asia and Pacific and a high of 20 for sub-Saharan Africa.

With average per capita incomes rising by 2.2 percent between 2005 and 2050, an income elasticity of 0.5 would yield an increase in food demand of 1.1 percent to be added to the 0.8 percent increase in population for a total increase of 1.9 percent. This simple estimate may be an overstatement as one would expect income elasticity for food to decline as incomes rise and is already near zero in most high-income countries. On the other hand, counter-balancing factors that would lead to a rise could be increasing demand for meat and dairy and new competition emerging from biofuels.

The factors behind demand growth are likely to be relatively stable compared with supply side variables. Ultimately, supply growth will be driven by the different degrees of intensification (getting more with the same amount of land) and extensification (expanding land under cultivation). The cost and availability of other inputs—notably water—are also important factors, but are more difficult to integrate into the current analysis.

[2] One might even argue that demand could even decline as health and environmental concerns lead to changing dietary habits and lower overall food consumption.

Using the latest available FAO data there is significant scope for extensification in many regions of the world (figure 4.3). Whether this potential supply is exploited or not will depend, among other factors, on the affordability of expansion in terms of infra-structure development and the potential negative externalities of expansion (e.g. environmental degradation). Which regions expand land use will also influence changes in the patterns of food trade. For example, Latin America, which has relatively large tracts of productive non-forest land available, could see a fairly rapid expansion of its production and exportable surplus.

The last few decades that has seen a huge increase in world population and yet stagnant or even falling agricultural prices, has been supported by sizeable improvement in agricultural productivity growth (Coelli and Rao 2005 and World Bank 2009), particularly in Asia, but in North America as well. This rapid growth has tapered somewhat more recently. For example yield growth in wheat and rice has declined from around 2 percent between 1965-1999 to less than 1 percent between 2000 and 2008. This is a cause for concern about the future, particularly as this decline has trended well with the decline in expenditures on research and development. There are available opportunities—in part because many regions are well behind the frontier, for example Europe and Central Asia and sub-Saharan Africa and also because the frontier can still be pushed out, notably with state-of-the-art gene-based research and development.

Part of our analysis of long-term trends relies on an analytical framework that allows us to integrate the various components of the description above—demographics, income growth, structural and taste changes, productivity and evolving factor supplies—into a consistent model of the global economy. The World Bank's model, known as ENVISAGE (ENVironmental Impact and Sustainability Applied General Equilibrium Model), is a dynamic computable general equilibrium (CGE) model (see Appendix 1 for a longer description of the model). It has several advantages. First, it is global with supply/demand balances guaranteed at the global level. Differences between domestic production and demand are met through exporting surpluses or importing to meet deficits. It also encompasses all economic activity. Hence, if a country becomes a net importer of food, it must export more of other commodities. And third, it is based on a consistent microeconomic underpinning facilitating what-if analysis. For example, what if productivity is higher or lower? What if demand for meat and dairy in developing countries follows a different pattern than for the high-income countries? What if energy prices rise? How does this affect the cost-structure of food supply? Will it induce more demand for biofuels? The remainder of this section explores some of these fundamental questions with the assistance of the model.

The baseline scenario, with productivity growth of 2.1 percent per annum in agriculture, yields a benign price pattern for overall agriculture, i.e. there is a small negative trend over the long-term with global supply/demand balances more or less lined-up (Figure 4.4). This has been the pattern for the last 30-40 years. Supply/demand balances at a regional level may widen as some countries have little room for expansion and also see a shift in comparative advantage in other goods. In the absence of new support policies, East Asia could see a relatively large increase in net agricultural imports with the high-income countries and Latin America and the Caribbean having exportable surpluses (figure 4.5).

Assumptions regarding productivity, as noted earlier, are key to determining potential stress on food markets. To assess the impact of the baseline assumption on agricultural productivity, two additional scenarios are undertaken. In the first scenario, developing countries are assumed to have half the productivity growth in agriculture compared with the baseline assumption. This could be driven by a number of factors including failure to ramp up research and development expenditures, resistance to genetically modified organism (GMO) technology, reduced effectiveness of inputs, lower land productivity (due to increasing salinity for example) or inadequate supply of water. The model suggests that in this case global agricultural prices would rise modestly compared to today's levels. However, it would also increase developing countries reliance on agricultural imports—with again rising dependence in Asia. Latin America and Caribbean remains as a net agricultural exporter.

If global productivity is halved, then agricultural prices rise by significantly more, nearly 35 percent above the base year in 2030 as compared with about 16 percent when only developing country agriculture is subjected to the lower productivity growth. The impact on trade balances is more mixed—lying in most cases between the baseline levels and the scenario where only developing country agriculture is impacted. Note that the net trade numbers are in value terms so that part of the change in the net trade will be induced by the change in the higher agricultural prices and is not simply a volume phenomenon.

## V. CLIMATE CHANGE

One issue that might be looming large in the next few decades is the impact of climate change on global agriculture. Some estimates suggest that a rise of 2.5 $^0$C could lower agricultural productivity by up to 40 percent, including in some very large countries such as India (Cline 2007). The net impact of climate change on agriculture is still being debated—at least at the global level. Some regions, notably the higher latitudes could benefit from longer growing periods, largely offsetting the damage in regions in the lower latitudes. There is also uncertainty regarding the impact of carbon fertilization. There is some evidence that higher concentrations of carbon may induce growth, at least to a certain point, and this could also potentially offset higher temperatures. Finally, though the general circulation models (GCMs) have a relatively high degree of consistency regarding temperature increases, there is much less consensus on rain patterns and the overall supply of water for agricultural purposes.

One of the features of the ENVISAGE model is that it incorporates the full cycle of greenhouse gas emissions from human activities, atmospheric concentrations and radiative forcing and changes in temperature. This class of models is also known as an Integrated Assessment Model (IAM). The model also couples changes in global temperature to economic damages. Currently, damages are only incurred in agriculture through impacts on agricultural productivity.

Figure 4.6 depicts how climate-induced agricultural damages are allocated across the globe based on the estimates produced by Cline. The figure clearly shows the concentration of damages in the lower latitudes and largely for developing countries. It represents in some sense a 'worse' case scenario in that it represents the damage estimates in the absence of the carbon fertilization effect. For the purposes of the baseline scenario, the damages have been assumed to be the average of the with- and without carbon fertilization effect. Cline's estimates are based on the assumption that the increase in temperature of 2.5 $^0$C will occur around 2080. This is based on scenarios developed at the end of the 1990s that have assumed a lower profile of emissions than that have been observed over the last decade, the current crisis notwithstanding. The damage functions in ENVISAGE are calibrated to Cline's estimated impacts for a temperature change of 2.5 $^0$C. For technical reasons we have specified and calibrated linear damage functions. This may overstate damages in the short-term, particularly in certain regions where warming could be beneficial, for example the higher latitudes, and understate damages in the long-run as many damage functions in the literature are assumed to be non-linear (see Nordhaus 2008 for example).

For the purposes of climate analysis the model runs through 2100, however for the purposes of this paper the focus will continues to be on the period that ends in 2030. In terms of atmospheric emissions, our projected emissions profile is significantly higher than most of those that form the basis of the climate change analysis as recently presented in the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC 2007). The scenarios in AR4 were generated around 2000 and largely underestimated both output and emission growth over the last decade. As a result, our baseline scenario shows much greater emission growth, and, if this pattern continues, puts the world on a trajectory with much higher temperature changes than the AR4 median of around 3 °C by the end of the century (Figure 4.7). With a higher temperature profile than the AR4 median, our estimates of the impacts from climate change on agriculture occur much earlier than assumed in the Cline study as the 2.5 $^0$C level is reached in 2050 and not in 2080.

The climate damages are built into the standard baseline. To isolate the impact of climate change an alternative scenario is simulated where the climate change damages are assumed away. All other exogenous assumptions are the same between the two scenarios. In this alternative scenario, agricultural productivity matches the exogenous assumption of 2.1 percent uniform growth with no deviation. The impacts on real income from climate damages even in 2030 could be substantial. South Asia would take the most significant hit—a loss in real income in 2030 of over 2 percent, more than double the loss of the next region, sub-Saharan Africa (Figure 4.8). The relatively large losses in these two regions reflect two factors. First, agriculture remains important despite relatively rapid economic growth. Second, the fact that existing studies suggest that the largest damages are occurring in these two regions – as summarized in Cline's (2007) estimates.

Finally, in this alternative scenario, the impact on high-income countries is negligible in the short-term. Partly, this arises from gains in the terms of trade as world prices rise in the with-damage scenario. The net trade position of all developing regions deteriorates in the with-damage scenario, albeit somewhat modestly in 2030, and improves (modestly) for high-income countries. In the long-run climate damages are bound to increase both because the climate will deteriorate and also due to non-linear effects (not currently captured in our model).

### Biofuels

The expansion of ethanol based on grain feedstock is quite different from that of sugar cane-based ethanol, especially in Latin America. In the later the tradeoff between food and fuel is quite limited. Moreover, sugarcane expansion would occur primarily in Latin America and then in other countries with low-cost sugar production. Most of this expansion will occur on land for which competition among crops is limited. By contrast, ethanol based on grains has a direct effect on several important competing crops, including oilseeds. The expansion of biodiesel as a strong and direct implication for vegetable oil prices and the feedstock and food demand are in direct competition. A large biodiesel expansion will push vegetable prices higher. Hence, the expansion of biofuel based on grains and oilseed products is a potential exacerbating factor for higher food prices and could compromise the access to food for the poorest on the planet. The most affected food prices would be grains, vegetable oils, meat, and dairy products which are intensive in feedstocks.

If cellulosic/biomass ethanol can become profitable, the tradeoff between food and fuel may be less important and confined to oilseed based biofuels. The development of biofuels is also determined by their return. The latter is largely determined by fossil energy prices and feedstock prices. Low fossil energy prices will undermine the development of large biofuel sectors and would reduce the tradeoff between food and fuel. Of course large and forced biofuel mandates could change this result. It is difficult to know what policies will prevail in 2050. Biofuels, both first and second generation, are currently being implemented in the model and will form the basis of further analysis.

## VI. POVERTY IMPLICATIONS

We have used the assumptions in the baseline scenario explained in section V to "roll" the global economy to 2050. In this section we'll concentrate on the global distributional effects behind the expected changes in per capita incomes and its distribution within countries[3]. To evaluate these distributional effects we rely on the World Bank's *Global Income Distribution Dynamics* (GIDD) model. The GIDD, a macro-micro simulation framework, is overviewed in Box 3 and explained in full detail in Bussolo, de Hoyos, and Medvedev (2008).

Figure 6.1 below plots Lorenz curves for the observed global income distribution in 2005 and the projected distribution in 2050. It appears that the largest changes in income distribution between 2005 and 2050 are expected to be found around the middle of the income distribution rather than towards the upper or lower tails. In fact, because the two Lorenz curves intersect in these tails, it is not possible to say that the 2050 distribution Lorenz-dominates that of 2005. In other words, we cannot claim that inequality in 2050 is lower as compared with 2005 regardless of the inequality measured being used. However, using standard inequality statistics such

[3] This section has been prepared relying on the methodology used in Bussolo et. al (2007) where the global economy was projected to 2030. Nevertheless, it has some minor variations: we are using the latest version of the GIDD (June, 2009) that has 2005 as a base year – instead of year 2000, and uses the latest Purchasing Power Parity conversion factors. As a result, slightly differences may emerge between the two documents, but these differences will not compromise the messages and authors' conclusions in any of them.

as the Gini, the Theil, and the mean logarithmic deviation – i.e. indicators that do not give too much weight to the extreme parts of the distribution – a marked reduction of inequality, as shown in Table 6.1, is recorded during the period considered here.

The remainder of this section analyzes the drivers of these expected distributional changes by means of three complementary approaches. First, we conduct the analysis in terms of the convergence and dispersion components, i.e. changes in income disparities between and within countries. This is taken up in the next two sub-sections, which show that the reduction in global income inequality between 2005 and 2050 is the outcome of two opposing forces: the inequality-reducing convergence effect and the inequality-enhancing dispersion effect. In other words, poor countries will catch up but it will come at a cost in terms of higher within-country and within-region income inequality (this is a trend experienced recently by China and India, see Ravallion and Chen, 2006). Second, we analyze the expected poverty effects of the new income distribution in 2050 with two approaches: the standard absolute poverty line of $1.25 dollars a day, and a weakly relative poverty line as suggested by Ravallion and Chen (2009). Third, since global poverty is expected to be substantially reduced by 2050, we analyze the emergence of a global middle class.

### VI.1 The dispersion and convergence component: while the poor world is catching up, intra-regional inequality is on the rise

The dispersion component should be understood as the outcome of all the changes outlined by the baseline scenario of section V, but keeping constant average incomes in each country. Within-countries, income distribution is expected to be altered by demographic changes, changes in skilled-to-unskilled wage premia, and rural-urban migration. In Figure 6.2 we plot non-parametric kernel densities of the global income distribution in 2005 together with the hypothetical distribution for the dispersion component, capturing only the changes in within-country inequality between 2005 and 2050. This hypothetical distribution was created by dividing household incomes in 2050 by the country-specific growth rate of the average incomes between 2005 and 2050. At the global level, distributional changes within countries in this hypothetical distribution almost with the original distribution having an almost neutral inequality effect on a global scale; with the income distribution barely increasing in Gini points (see Table 6.1).

In the other hand, the convergence component takes into account each country's income variation as projected from the baseline scenario of section V, but maintains global average income constant. There are three aspects determining the existence, sign, and magnitude of each country's contribution to the convergence component: (1) a particular country will have a global distributional impact if its rate of growth differs from the global average; (2) given that condition (1) is satisfied, the sign of the distributional effect will depend on the country's initial position in the global distribution; and (3) the magnitude of the impact is determined by the size of the growth rate differentials (with respect the global average) and the country's share in the global population. Hence, initial poor countries with higher-than-average growth rates will have an inequality-reducing effect with a magnitude determined by the size of the country's population.

Figure 6.3 shows the change of the global income distribution due to differences in growth rates between countries when global average income is kept constant. Had the convergence effect been the only change taking place between 2005 and 2050, global inequality would have been reduced by 8.0 Gini points (see Table 6.1). This means that the improvement in the global income distribution reported can be mainly explained by growth rate differentials across countries with poor countries catching up with middle- and high-income countries.

### VI.2 Poverty

Measurement of global poverty in developing countries has typically been based on absolute poverty measures. The typical practice for an absolute measure is to set a monetary quantity, called poverty line, which represents the minimum income needed to acquire a set of goods that will suffice some established basic human needs. Poverty lines are typically based on the food needed to attain a recommended daily caloric ingestion. In addition to these basic poverty lines, some countries draw complementary ones drawn to set the minimum income needed to suffice more complex human needs i.e. health and education. At the global level, the World Bank's "$1 and $2-a-day" are the best known example of absolute poverty lines.

Alternatively, the common practice in OECD countries is to use relative poverty lines. These monetary quantities are periodically adjusted, not as the minimum income needed to acquire a given basket of goods, but as a constant proportion of the countries' mean or median incomes. The first argument to use relative poverty measures over absolute ones relies on the "welfarist" assumption that people attach value to their own income relative to the average in its own society – often cited as the "theory of relative deprivation" or the "relative income hypothesis". The second argument in favor of relative poverty lines is that they allow for differences in the cost of social inclusion. Following Ravallion and Chen (2009) these are defined as the expenditure needed to cover certain commodities that are deemed to have a social role in assuring that a person can participate with dignity in customary social and economic activities.

Despite the two cited arguments in favor of relative rules to measure poverty trends, they have not been used for the study of poverty in very low income countries because they possess the property of scale independency, in other words, if all incomes in a society grow at the same rate, no change in poverty will occur.

Ravallion and Chen (2009) discuss all these aspects rigorously and outlined an alternative measure. With the use of a large sample of poverty lines collected by the World Bank, they calibrate a new measure for the study of global poverty called weakly poverty line. The proposed weakly relative poverty line is, in general terms, a combination of the two previous approaches: (1) For very low levels of income, it functions as an absolute poverty line set to the World Bank's $1.25 a day (in purchasing power parities of 2005). (2) For medium and higher incomes, it functions as a relative poverty line. The empirical implementation followed the formula:

$$Zi \equiv \max\left[\$1.25, \alpha + \frac{M_i}{3}\right] \tag{5.1}$$

where $Z_i$ is the value of the poverty line, $M_i$ is the mean daily income in country *i*, and $\alpha$ was estimated by Ravallion and Chen (2009) to be PPP $0.60. The advantage of using the weakly relative poverty line is that it will provide a better understanding about poverty and exclusion in the projected income distribution in 2050 than the absolute poverty measure. Table 6.2 summarizes the regional headcount ratio of absolute and weakly relative poverty in 2005 and 2050. While absolute poverty vanishes in the planet, weakly relative poverty still accounts for a large share of the population, especially in underperforming Latin America. According to our baseline scenario, the increase in weakly relative poverty reported by Ravallion and Chen (2009) experienced during the late 1980s and until the year 2000 is reversed by year 2050 in almost all regions. Table 6.2 shows the headcount index for absolute and weakly relative poverty in 2005 and 2050 as well as the change in the number of poor in both periods.

The most interesting result is that while other nations are performing relatively well, Latin America is the only region where the number of weakly relative poor actually increases (67 million), partly reflecting that it is the most unequal region in the planet. Within Latin America and the Caribbean, the only countries that have a net reduction in the number of relative poor are Guyana, Peru, and Haiti with a joint reduction of 4.5 million. All other countries will see the number of relative poor increasing, Mexico being the most affected. Mexico alone accounts for half of the increase in the number of relative poor in Latin America, followed by Brazil (11 million), Ecuador (4.8 million), and Colombia (4 million).

In sub-Saharan Africa, absolute poverty is expected to be reduced from 51.2 to 2.8 percent of the population; and remarkably, weakly poverty from 55.5 to 20.3 percent of the population. The country that will perform the better is United Republic of Tanzania that will reduce in almost 70 percent its relative poverty rate with an absolute negative change of 20 million living in relative poverty. In addition, Nigeria and Ethiopia will reduce drastically the net number of poor in 34 and 20 million respectively; but in relative terms, the best performers are Malawi, Burundi, Guinea, and Rwanda; all of them with relative poverty reduction rates above the 50 percent points.

### VI.3 The new middle class and beyond

Alternatively to the study of global poverty, the emergence of countries in the new middle class is of high importance because the expected changes in global consumption patterns accompanied by economic growth. Certainly, individuals in 2050 will be healthier and more educated, with higher expectations about their role in life, greater political participations, and increasingly more complex needs. As a result, the demand for more and better goods and services will rise as vast number of families emerges from poverty in developing countries. Bussolo et al., (2007) uses a definition of absolute global middle class (GMC) that we will use in order to quantify the number of people that will be part of this group in the hypothetical income distribution in 2050. The GMC will be defined as the world citizens living with incomes between the current Brazilian and Italian averages.

The GMC will grow from around 450 million in 2005 to 2.1 billion in 2050, and from 8.2 to 28.4 percent of the global population (Table 6.3). Furthermore, the composition of this group of consumers is likely to change radically: while in 2005, developing country nationals accounted for 56 percent of the GMC, by 2050 they are likely to represent nearly the totality of this group. The biggest contributors to the increase in the number of the GMC members are the most populous Asian countries led by China and India. These two countries alone are responsible for nearly two-thirds of the entire increase in the GMC, with China accounting for 30 percent of the rise in the GMC population and India adding another 35 percent. More surprisingly is that as a result of the sustained economic growth in China and according to the scenario depicted in section V, by 2050, 40 percent of the Chinese population will surpass the global middle class status.

There are several reasons behind the dramatic increase projected in the size of the GMC and the major shift in composition in favor of the low- and middle-income countries. Faster population growth in the developing world is responsible for some of the change in the composition. Thus regions with population growth above the world average (for example, South Asia and sub-Saharan Africa) will increase their share in the global middle class. The main determinant of joining the middle class ranks, however, is not population growth but income growth. Although East Asia's population grows more slowly than the world average, this region is projected to increase its share of residents in the global middle class by more than 30 percent points, compared with 15 percent points in sub Saharan Africa. The difference is due to the fact that annual per capita income growth in Asia is forecasted to be more than twice the growth in sub-Saharan Africa, easily offsetting the decline in the former's population share.

Most developing-country members of today's (as of 2005) global middle class earn incomes far above the averages of their own countries of residence. In other words, being classified as middle class at the global level is equivalent to being at the top of the distribution in many low-income countries. For example, in our sample, as of 2005, 180 million (out of the total 260 million) developing country citizens in the global middle class are in the top 20 percent of earners within their own countries. Thus, for many nations, the correspondence between the global middle class and the within-country middle class is quite low. The situation will change quite dramatically by 2050. A full 60 percent of developing country members of the global middle class will be earning incomes in the seventh decile or lower at the national level. Consider the example of China, where 27 million people belonged to the global middle class in 2005—each of them earning more than 90 percent of all Chinese citizens. By 2050, there will be 517 million Chinese in the global middle class, and their earnings will range from the fifth to the ninth decile of the Chinese national income distribution.

Consistent with these data, by 2050 the middle class, together with the rich, will account for a larger share of the population in a greater number of countries. In 2005, the members of middle class and the rich group exceeded 40 percent of the population in only six developing countries (Azerbaijan, Chile, Costa Rica, Hungary, Mexico, and Uruguay) these countries were home to 3.0 percent of the population of the developing world. By 2050, the middle class and the rich will exceed 40 percent of the population in 58 developing countries (as they are classified today), and these countries will account for 72 percent of the world's developing country population.

## VII. CONCLUSIONS

At a minimum, the price spikes of 2007-2008 shook global complacency as regards agriculture after a period of neglect driven in part by globally benign price changes and no major supply disruptions. Experts were aware about the fall in agricultural productivity growth and expenditures on research and development, but in a crowded field of international economic policy issues, the warning signs were largely ignored. As regards agriculture, the focus has been much more on farm support policies and trade barriers than on fundamental supply issues. Are we now witnessing a structural shift, with higher and growing agricultural prices, or was 2007-2008 just a bump in the road. This paper suggests that the answer lies somewhere in between. There is a structural shift with a greater linkage to energy markets than in the past. Higher energy prices could induce a stronger shift to biofuels with competing pressures on resources and higher food prices. Potentially this linkage could be strengthened if climate mitigation policies raise the end-use price of conventional fossil fuels and induce a further substitution into biofuels. At the same time, there are reasons to believe that the world can adjust to these imminent changes. Declining population growth and food saturation will temper food demand growth in the future and health and environmental concerns could even induce a shift in tastes that would temper demand even further. There is also sufficient land that would allow for some expansion, if managed appropriately and sustainably. It will require investment in infrastructure, which could be onerous, particularly in the poorer parts of the world. The ability to raise productivity is also a concern, particularly in an environment with growing climate stress. Again, it will require resources to enhance research and development, with perhaps an emphasis on regions where productivity lags far behind best practices.

However, even if there is manageable stress at the global level, the changing environment at a regional level is likely to have distributional repercussions both across and within countries. Managing these stresses may be more difficult as food security at both the household and national level are often priorities for policy makers. And as we witnessed in the most recent crisis, policy makers, naturally, will make the most rational decisions for their stakeholders even if better overall policies could be implemented with the right coordination.

**BOX 1: Experience with Managing Commodity Markets**

The long-term declines along with high variability of commodity prices prompted many governments to take collective measures to either prevent the decline or reduce the variability. Coffee producers, led by Brazil, organized the 1962 International Coffee Agreement (and a subsequent series of agreements) to restrict exports and boost coffee prices. Similar efforts were undertaken by cocoa producers while attempts were also made in other markets (e.g. cotton, grains). The oil producers formed the Organization of Petroleum Exporting Countries (OPEC) in 1960 in order to raise prices through supply controls. Similarly, buffer stocks were used by organizations of commodity producing countries in order to stabilize prices. Tin producers, through the International Tin Agreement managed buffer stocks to maintain prices within a range. The International Cocoa Agreement, form in 1972, also attempted to stabilize prices through buffer stocks but was suspended in 1988. The International Natural Rubber Organization was formed to stabilize rubber prices but major producers withdrew from the Organization following the East Asia financial crisis of 1997. With the exception to OPEC, all these agreements failed to achieve their stated objectives as coordination and monitoring among many sovereign nations turned out to be a difficult task. In addition to the post-WWII commodity agreements, there was another wave of agreements that were formed in response to the low prices following the Great Depression.

**BOX 2: The Role of Speculation during the Recent Commodity Boom**

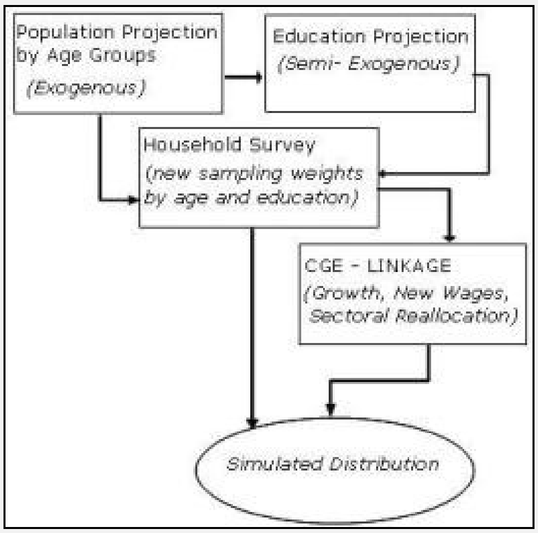
Since 2003 index fund investors, who allocate funds across a basket of commodities by taking long positions various commodities traded in organized futures exchanges, have invested almost $250 billion in U.S. commodity markets, about half of it in energy commodities (Masters 2008). While such transactions are not associated with real demand for commodities, they may have influenced prices for a number of reasons. First, because investment in commodities is a relatively new phenomenon, there have been mostly inflows (not outflows) of funds implying that some markets may have been subjected to extrapolative price behavior (i.e., high prices leading to more buying by investment funds consequently leading to even higher prices, and so on). Second, these funds invest on the basis of fixed weights or past performance criteria and hence investment often takes places in contrast to what market fundamentals would dictate. Third, the large size of these funds compared to commodity markets may exacerbate price movements. Their influence on prices is especially likely, if the rapid expansion of these markets contributed to expectations of rising prices, thereby exacerbating swings, as argued by Soros (2008, p. 4) who called commodity index buying "... intellectually unsound, potentially destabilizing and distinctly harmful in its economic consequences." Similar views are shared by numerous authors (see for example, Eckaus (2008) and Wray (2008)).

Yet, the empirical evidence on whether such funds contributed to the price boom has been, at best, mixed. In the non-ferrous metal market, Gilbert (2008) found no direct evidence of the impact of investor activity on the prices of metals but some evidence of extrapolative price behavior that resulted in price movements not fully justified by market fundamentals. He also found strong evidence that futures positions of index providers over the past two years have affected the soybean (but not the maize) prices in the US futures exchanges. Plastina (2008) concluded that between January 2006 and February 2008, investment fund activity might have pushed cotton prices 14 percent higher than what would have been otherwise. On the other hand, two IMF (2006, 2008) studies failed to find evidence that speculation has had a systematic influence on commodity prices. A similar conclusion was reached by a series of studies undertaken by the Commodities Futures Trading Commission, the agency that regulates U.S. futures exchanges (Büyükşahin, Haigh, and Robe 2008; CFTC 2008).

Although the empirical evidence regarding the effect of investment fund activity is mixed and inconclusive, the large amount of money that does into commodities certainly has an effect on prices, which is the consensus among experts. On the other hand, market fundamentals will determine the long-term trends of commodity prices, which implies that investment fund activity has induced higher price variability.

**BOX 3: The Global Income Distribution Dynamics model**

The World Bank Development Economics Prospects Group (DECPG) has developed the Global Income Distribution Dynamics (GIDD), the first global CGE-microsimulation model. The GIDD takes into account the macro nature of growth and of economic policies and adds a microeconomic—that is, household and individual—dimension to it.




The GIDD includes distributional data for 121 countries and covers 90 percent of the world population. Academics and development practitioners can use the GIDD to assess growth and distribution effects of global policies such as multilateral trade liberalization, policies dealing with international migration and climate change, among others. The GIDD also allows analyzing the impacts on global income distribution from different global growth scenarios and to distinguish changes due to shifts in average income between countries from changes attributable to widening disparities within countries.

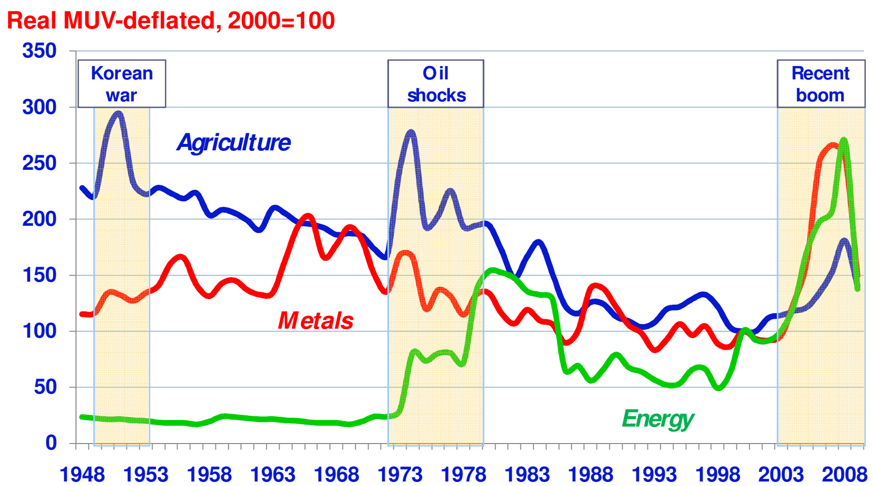
The macro-micro modeling framework described here explicitly considers long-term time horizons during which changes in the demographic structure may become a crucial component of both growth and distribution dynamics. The GIDD's empirical framework is schematically represented in the figure to the left.

The expected changes in population structure by age (upper left part of the figure) are exogenous, meaning that fertility decisions and mortality rates are determined outside the model. The change in shares of the population by education groups incorporates the expected demographic changes (linking arrow from top left box to top right box in the figure). Next, new sets of population shares by age and education subgroups are computed and household sampling weights are re-scaled according to the demographic and educational changes above (larger box in the middle of the figure). The impact of changes in the demographic structure on labor supply (by skill level) is incorporated into the CGE model, which then provides a set of link variables for the micro-simulation:

(a) change in the allocation of workers across sectors in the economy,
(b) change in returns to labor by skill and occupation,
(c) change in the relative price of food and non-food consumption baskets, and
(d) differentiation in per capita income/consumption growth rates across countries.

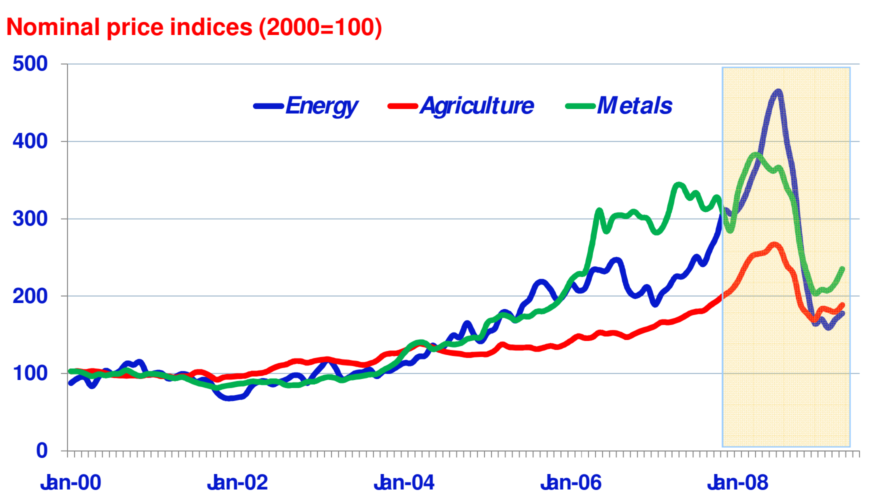
The final distribution is obtained by applying the changes in these link variables to the re-weighted household survey (bottom link in the figure).

**Figure 2.1: Unlike earlier booms, the current boom involved all commodity groups**



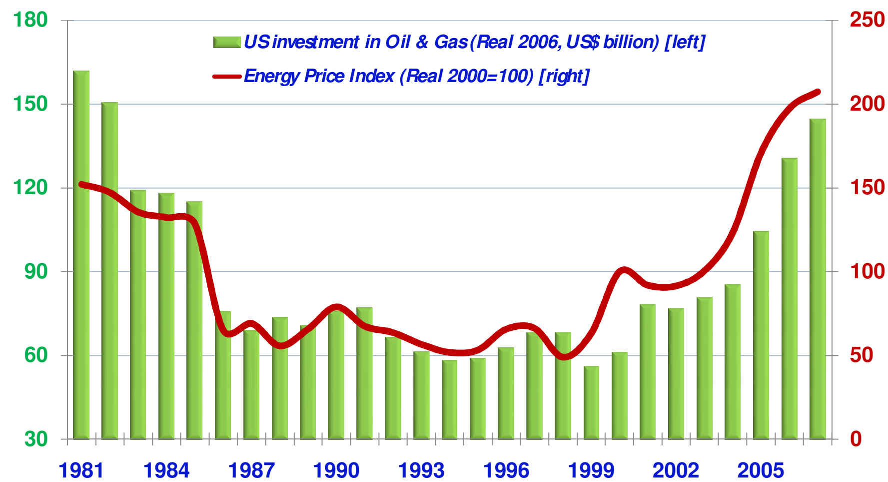

Source: World Bank

**Figure 2.2: All commodity prices have declined sharply since the mid-2008**



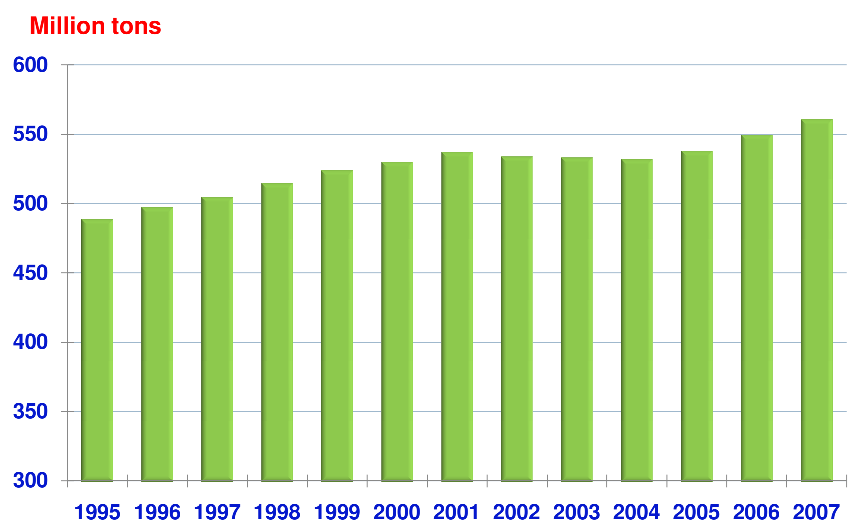

Source: World Bank

**Figure 2.3: Investment by major multinational oil companies follows energy prices**



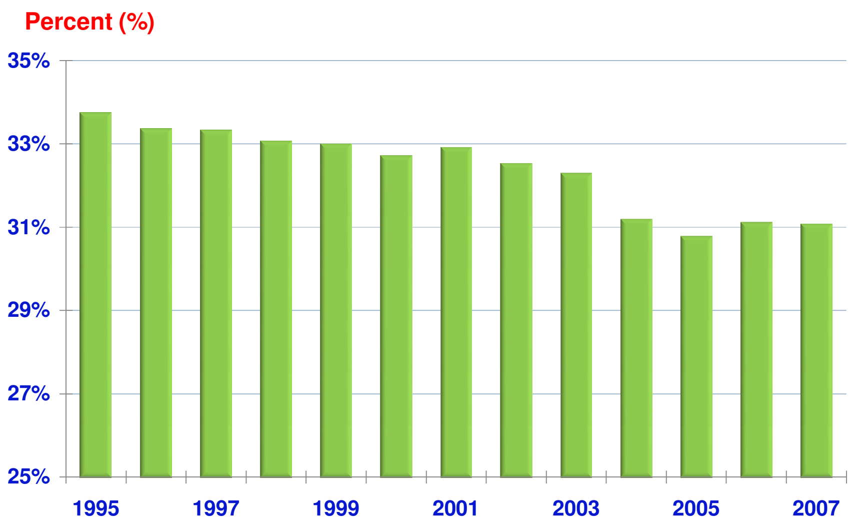

Source: International Energy Agency and World Bank

**Figure 2.4: Total grain consumption by China and India (rice, maize, wheat)**



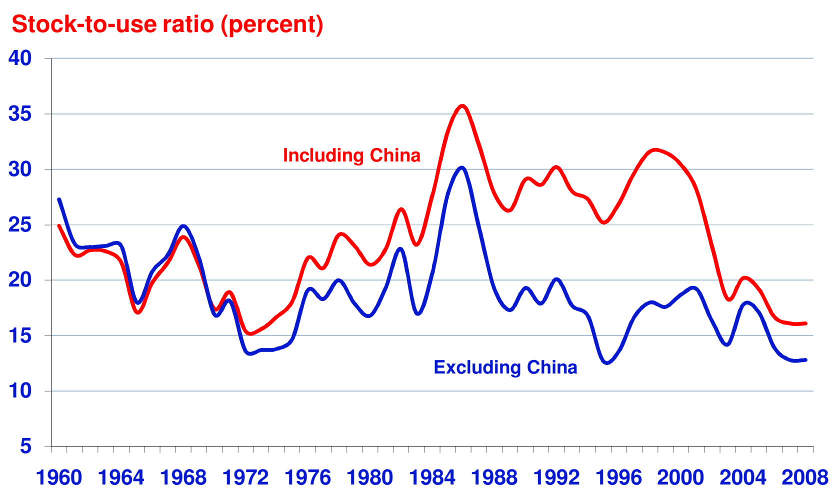

Source: World Bank calculations based on FAPRI data

## Figure 2.5: Grain consumption by China and India as percent of world's total (rice, maize, wheat)



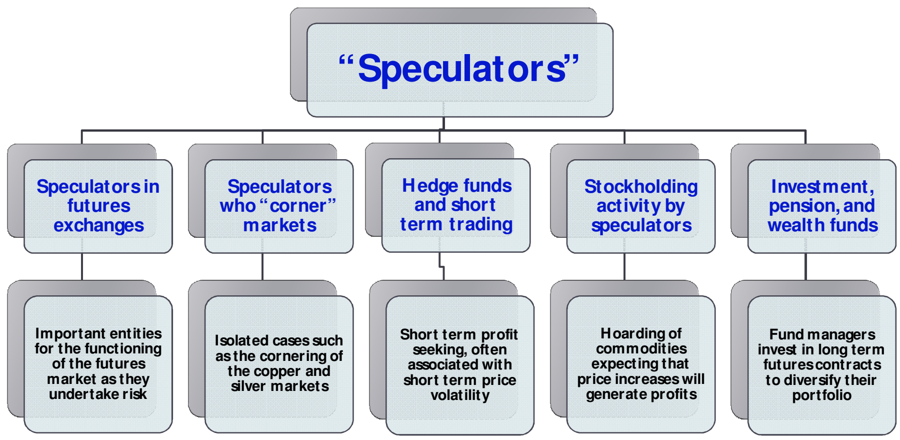

Source: World Bank calculations based on FAPRI data

## Figure 2.6: Global grain stocks declined to levels not seen since the mid-1970s




Source: World Bank calculations based on USDA data

Figure 2.7: "Speculation" and commodity markets




Source: World Bank

**TABLE 2.1: INCOME ELASTICITIES**

| | *Low Income* | *Lower Middle Income* | *Upper Middle Income* | *High Income* |
|---|---|---|---|---|
| ***Grains*** | 0.15 | 0.10 | 0.05 | -0.01 |
| ***Vegetable Oils*** | 0.50 | 0.65 | 0.78 | 0.41 |
| ***Meats*** | 0.31 | 0.51 | 0.68 | 0.38 |

**Notes:** The estimates are based on panel estimation.

**Source:** Authors' estimates.

**TABLE 3.1: PARAMETER ESTIMATES, PRICE INDICES**

| *INDEX* | $\mu$ | $\beta_1$ | $\beta_2$ | $100^*\beta_3$ | *Adj-$R^2$* | *ADF* |
|---|---|---|---|---|---|---|
| **Non-Energy** | 3.03@ (6.54) | 0.28@ (5.24) | 0.12 (0.68) | -0.01 (0.02) | 0.90 | -3.35** |
| ***Metals*** | 3.77@ (4.80) | 0.25@ (3.14) | -0.17 (0.60) | 1.93@ (2.31) | 0.82 | -3.30** |
| ***Fertilizers*** | 3.58@ (4.12) | 0.55@ (4.79) | -0.30 (0.95) | 0.39 (0.48) | 0.81 | -3.97*** |
| ***Agriculture*** | 2.51@ (6.90) | 0.26@ (5.54) | 0.33@ (2.43) | -0.99@ (2.73) | 0.90 | -3.81*** |
| *Beverages* | 1.83@ (3.10) | 0.38@ (4.87) | 0.55@ (2.63) | -3.12@ (5.22) | 0.76 | -4.95*** |
| *Raw materials* | 1.85@ (4.16) | 0.11@ (2.15) | 0.51@ (3.15) | 0.08 (0.19) | 0.91 | -3.15** |
| *Food* | 2.91@ (7.11) | 0.27@ (4.93) | 0.21 (1.39) | -0.71 (1.80) | 0.85 | -3.85*** |
| Cereals | 3.13@ (5.94) | 0.28@ (4.23) | 0.17 (0.89) | -0.87 (1.76) | 0.78 | -3.83*** |
| Edible oils | 3.33@ (6.16) | 0.29@ (4.51) | 0.12 (0.58) | -0.80 (1.50) | 0.80 | -2.82* |
| Other food | 1.86@ (6.28) | 0.22@ (3.81) | 0.45@ (4.44) | -0.42 (1.18) | 0.89 | -3.60*** |
| **Precious metals** | -1.40@ (3.58) | 0.46@ (9.40) | 1.05 (7.61) | -1.75 (3.68) | 0.98 | -3.91*** |

**Notes**: The @ sign denotes parameter estimate significant at the 5 percent level while the numbers in parentheses are absolute *t-values* (the corresponding variances have been estimated using White's method for heteroskedasticity-consistent standard errors.) ADF denote the MacKinnon one-sided *p-values* based on the Augmented Dickey-Fuller equation (Dickey and Fuller 1979). One (*), two (**), and three (***) asterisks indicate rejection of the existence of one unit root at the 10 percent, 5 percent, and 1 percent levels of significance (the respective *t-statistics* are -2.60, -2.93, and -3.58). The lag length of the ADF equations was determined by minimizing the Schwarz-loss function.

Source: Author's estimates.

## TABLE 3.2: COMPARING LONG-RUN TRANSMISSION ELASTICITIES

| | *Holtham (1988) 1967:S1-1984:S2* | *Gilbert (1989) 1965:Q1-1986:Q2* | *Borensztein & Reinhart (1994) 1970:Q1-1992:Q3* | *Baffes (2007) 1960-2005* | *This Study 1960-2008* |
|---|---|---|---|---|---|
| ***Non-energy*** | — | 0.12 | 0.11 | 0.16 | 0.28 |
| ***Food*** | — | 0.25 | — | 0.18 | 0.27 |
| ***Raw materials*** | 0.08 | — | — | 0.04 | 0.11 |
| ***Metals*** | 0.17 | 0.11 | — | 0.11 | 0.25 |

**Notes:** Holtham uses semiannual data, Gilbert and Borensztein & Reinhart quarterly, and Baffes along with the present study annual. Gilbert's elasticities denote averages based of four specifications. Holtham's raw materials elasticity is an average of two elasticities based on two sets of weights. '—' indicates that the estimate is not available.

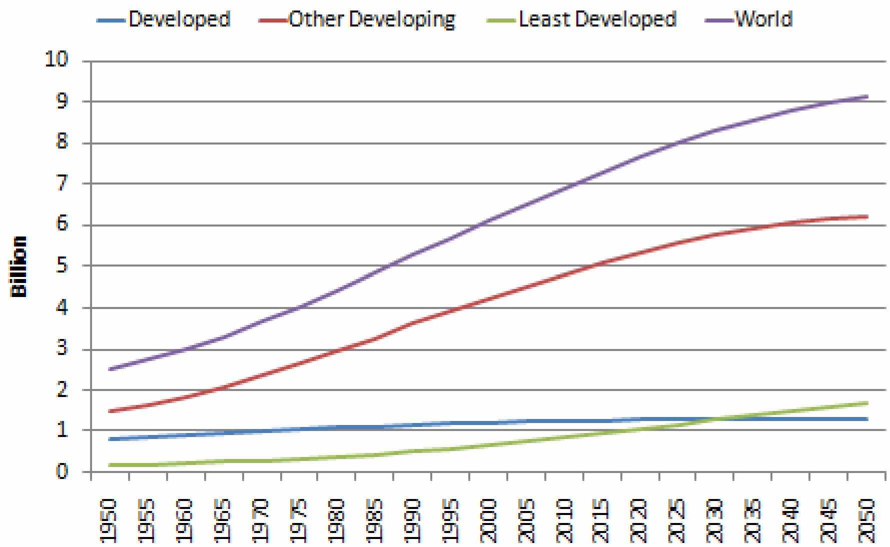
**Source:** Holtham (1988), Gilbert (1989), Borensztein and Reinhart (1994), Baffes (2007), and author's estimates.

## TABLE 3.3: PARAMETER ESTIMATES, INDIVIDUAL COMMODITIES

| *COMMODITY* | $\mu$ | $\beta_1$ | $\beta_2$ | $100^*\beta_3$ | *Adj-$R^2$* | *ADF* |
|---|---|---|---|---|---|---|
| Wheat | 3.27@ (6.50) | 0.30@ (5.02) | 0.12 (1.49) | -0.49 (1.07) | 0.84 | -4.35** |
| Maize | 3.15@ (6.23) | 0.27@ (4.66) | 0.13 (0.70) | -0.74 (1.58) | 0.80 | -3.49** |
| Soybeans | 3.58@ (8.11) | 0.26@ (4.92) | 0.25 (1.51) | -0.82 (1.83) | 0.82 | -3.85*** |
| Rice | 3.57@ (5.14) | 0.25@ (2.67) | 0.32 (0.26) | -1.62@ (2.78) | 0.58 | -4.05*** |
| Palm oil | 4.94@ (6.44) | 0.35@ (3.72) | -0.01 (0.02) | -0.95 (1.38) | 0.63 | -3.16** |
| Soybean oil | 5.25@ (7.83) | 0.36@ (4.13) | -0.09 (0.39) | -0.42 (0.53) | 0.70 | -2.56 |

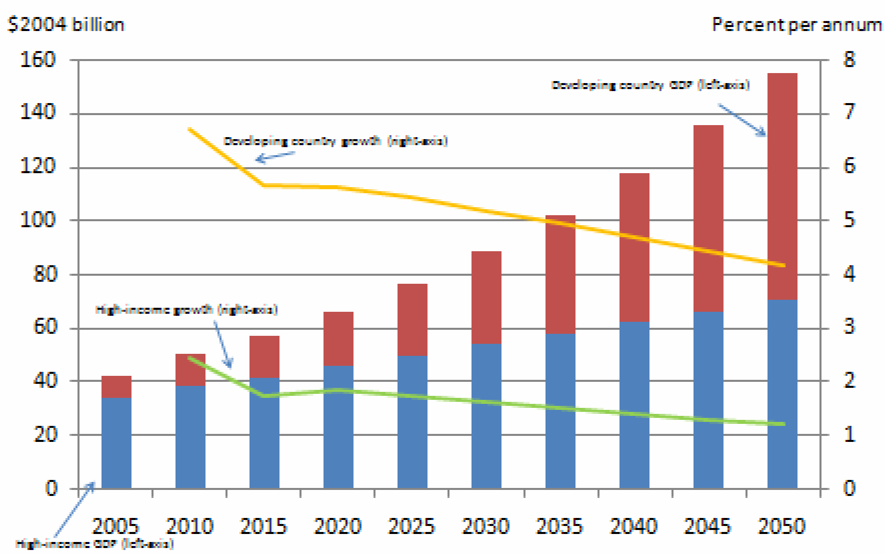
**Notes**: See table 3.1

Figure 4.1 Population history and projection



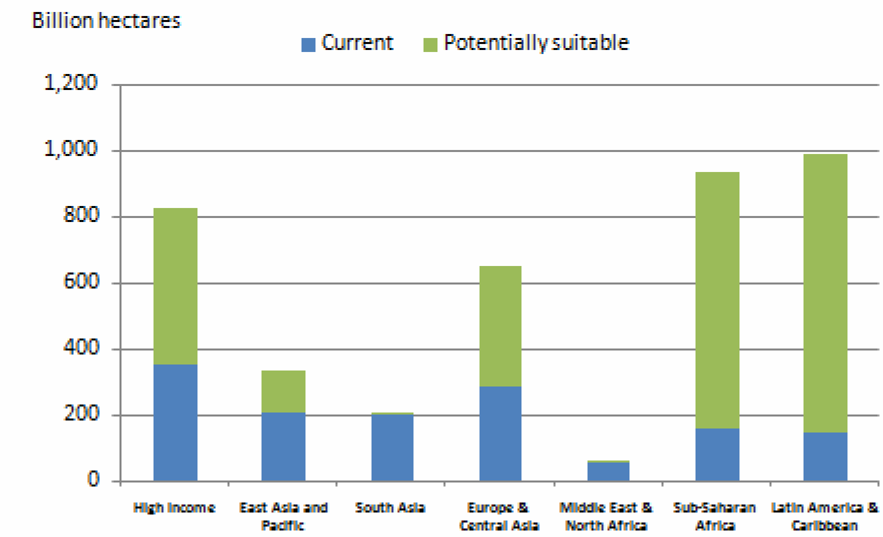

*Source*: UN Population Division (http://esa.un.org/unpp/index.asp).

Figure 4.2: GDP growth scenario



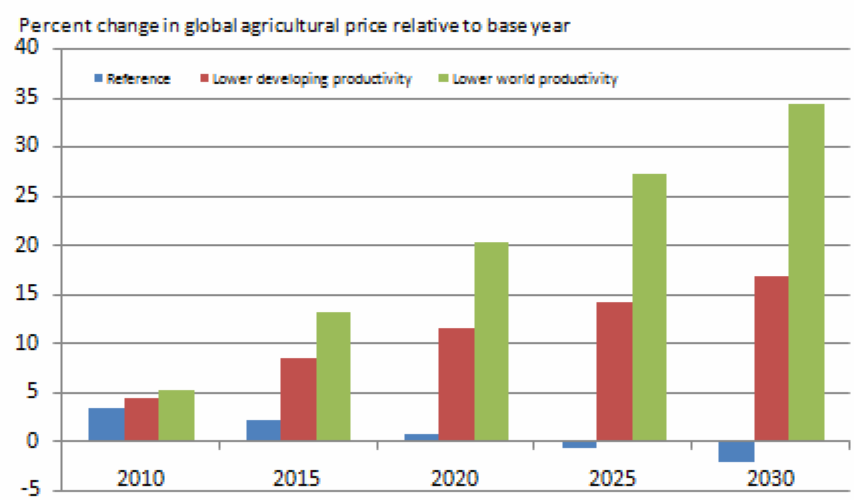

*Source*: Simulation results with World Bank's ENVISAGE model.

Figure 4.3: Land under cultivation and potentially suitable



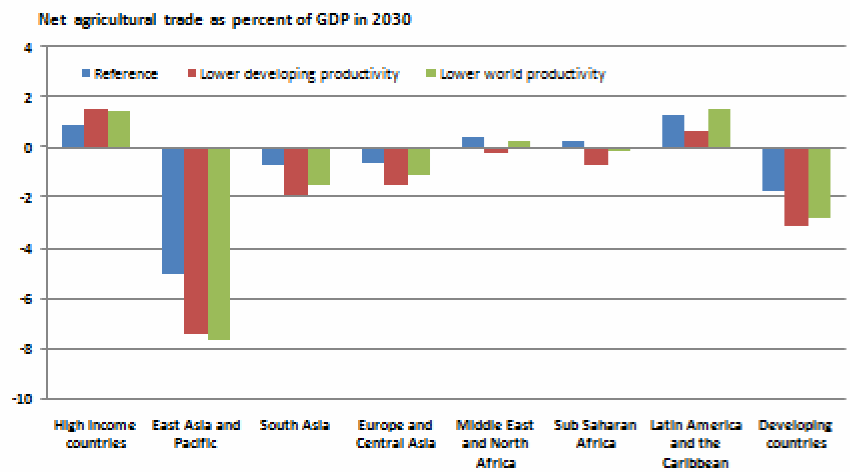

*Source*: FAO.

Figure 4.4: World agricultural prices are sensitive to productivity assumptions



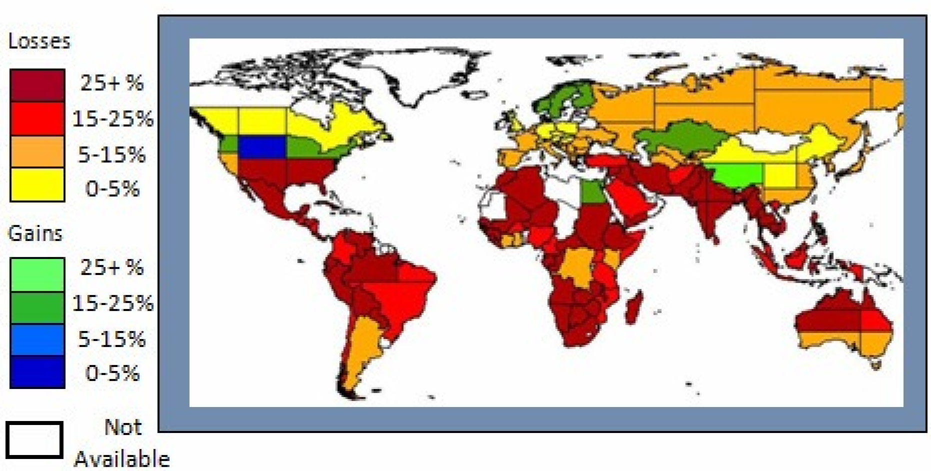

*Source*: Simulation results with World Bank's ENVISAGE model.

Figure 4.5: Net agricultural trade could change substantially for some regions



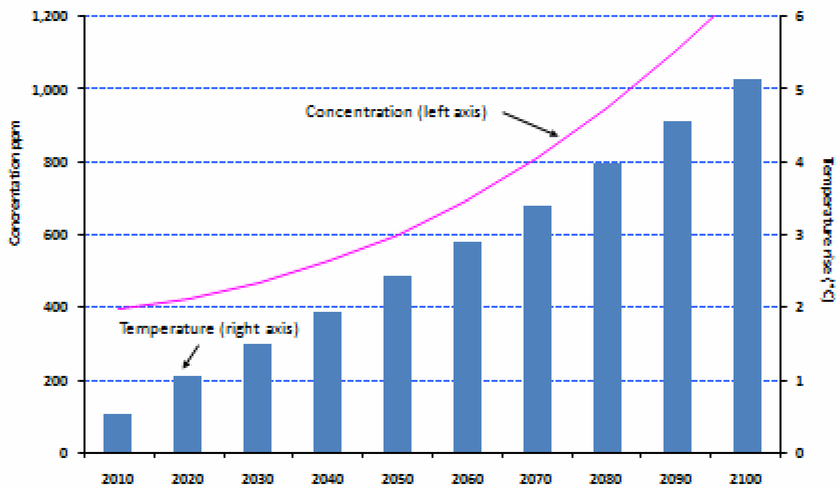

*Source:* Simulation results with World Bank's ENVISAGE model.

Figure 4.6: Potential impact on agricultural production due to climate change—without carbon fertilization effect




*Source:* Cline 2007.

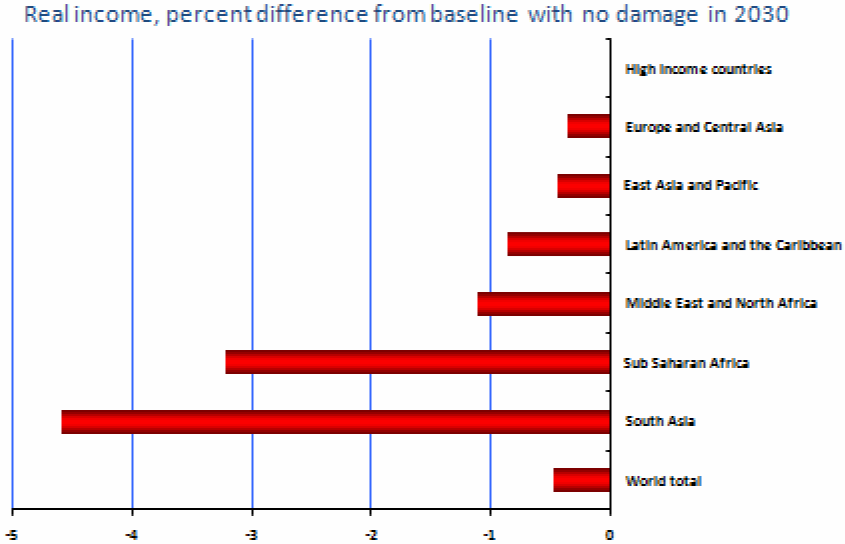
Figure 4.7: Concentration and temperature in baseline




*Source:* Simulation results with World Bank's ENVISAGE model.

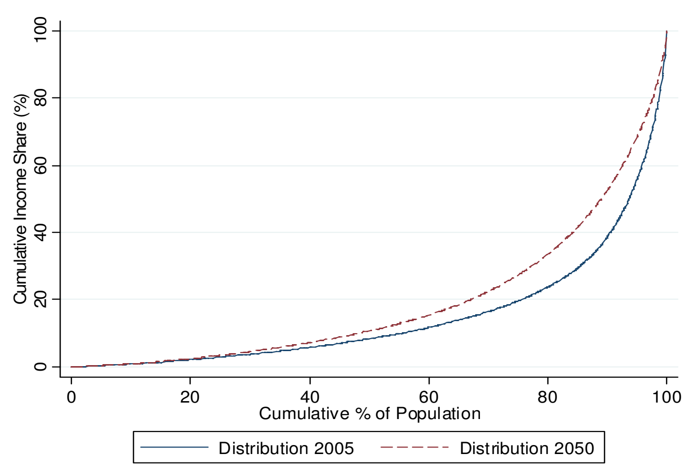
Figure 4.8: Potential impact of climate change

Real income, percent difference from baseline with no damage in 2030




Source: Simulations with World Bank's ENVISAGE model.

Figure 6.1 Lorenz Dominance: Changes in the middle of the distribution




Source: Authors' calculations

Source: Authors' estimates

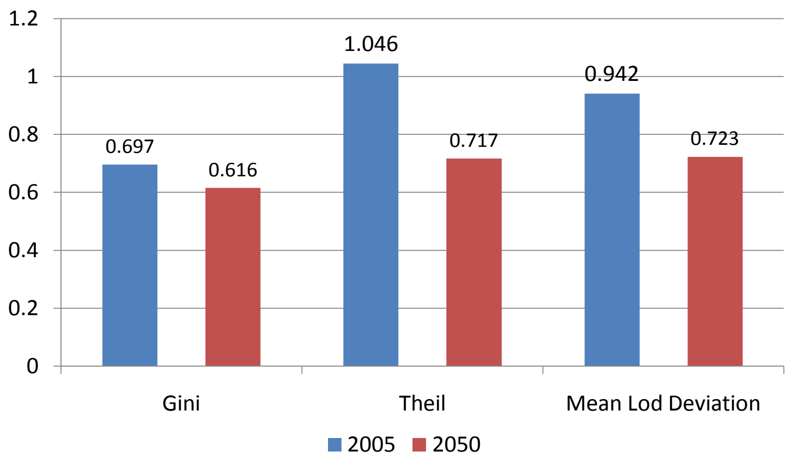
Table 6.1 Global Income Inequality

| Index | 2005 | 2050 | Dispersion Only | Convergence Only |
|---|---|---|---|---|
| Gini | 0.697 | 0.616 | 0.701 | 0.616 |
| Theil | 1.046 | 0.717 | 1.059 | 0.719 |
| Mean Log Deviation | 0.942 | 0.723 | 0.954 | 0.723 |

| | **Gini** | | **Theil** | | **Mean Log Dev** | |
|---|---|---|---|---|---|---|
| **Region** | **2005** | **2050** | **2005** | **2050** | **2005** | **2050** |
| *Developed Countries* | *0.394* | *0.378* | *0.270* | *0.245* | *0.277* | *0.257* |
| *Developing Countries* | *0.552* | *0.588* | *0.623* | *0.664* | *0.529* | *0.629* |
| East Asia and the Pacific | 0.421 | 0.479 | 0.311 | 0.399 | 0.293 | 0.411 |
| Eastern Europe and Central Asia | 0.394 | 0.513 | 0.257 | 0.441 | 0.280 | 0.490 |
| Latin America and the Caribbean | 0.599 | 0.605 | 0.714 | 0.707 | 0.699 | 0.719 |
| Middle East and North Africa | 0.399 | 0.405 | 0.284 | 0.298 | 0.261 | 0.271 |
| South Asia | 0.297 | 0.326 | 0.156 | 0.183 | 0.141 | 0.176 |
| Sub Saharan Africa | 0.495 | 0.488 | 0.499 | 0.481 | 0.425 | 0.410 |

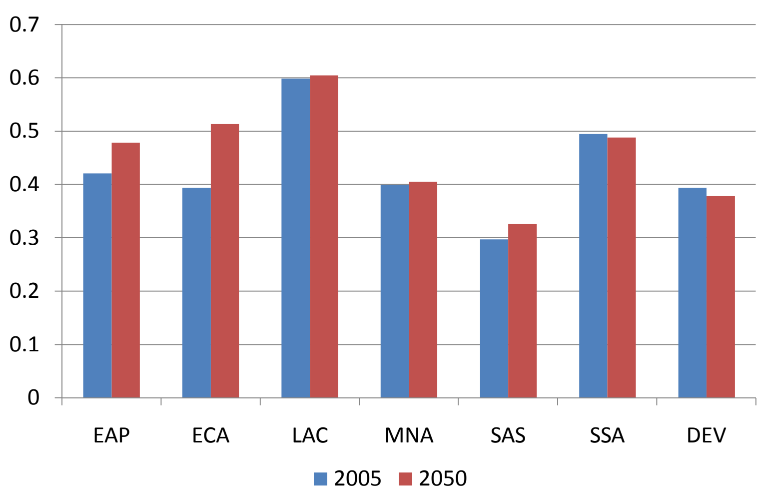
Data source: Authors' estimates

Figure 6.2 Global Income Inequality reduction, while…



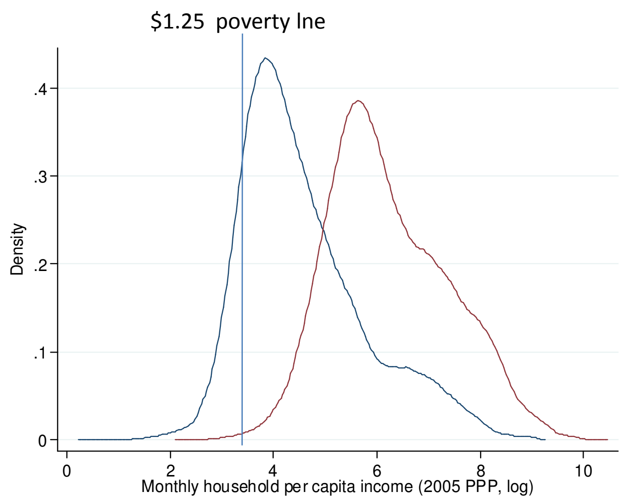

Source: Authors' calculations

Figure 6.3 Within-region income inequality on the rise



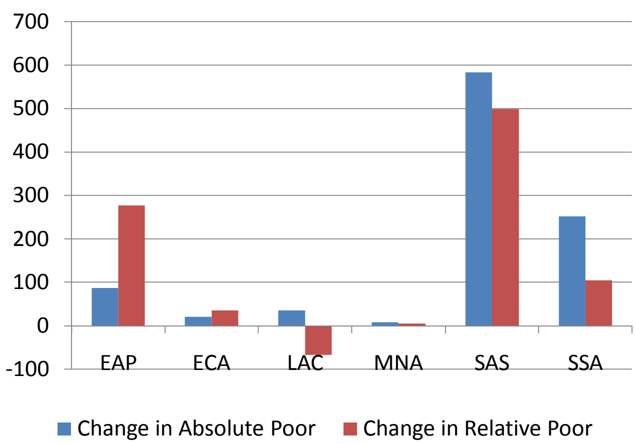

Source: Authors' calculations

Figure 6.4 Income distribution in 2005 and 2050:
Reduction of absolute poverty




Source: Authors' calculations

Figure 6.5 Reduction in absolute vs relative poverty




Source: Authors' calculations

Relative Poverty Measured as Ravallion and Chen (2009) *"Weakly Relative Poverty"*

**Table 6.2 Poverty Estimates**

| | Absolute Poverty ($1.25 PPP) | | | Weakly Relative Poverty | | |
|---|---|---|---|---|---|---|
| | Head Count Index (2005) | Head count Index (2050) | –Δ Poverty Millions | Head Count Index (2005) | Head count Index (2050) | –Δ Poverty Millions |
| *All Developing Countries* | 21.9 | 0.4 | 1,185 | 31.96 | 12.4 | 843 |
| East Asia and the Pacific | 15.8 | 0.0 | -87 | 30.4 | 12.1 | 277 |
| Eastern Europe and Central Asia | 4.4 | 0.0 | 20 | 12.6 | 5.5 | 35 |
| Latin America and the Caribbean | 8.1 | 1.0 | 35 | 33.3 | 31.3 | (67) |
| Middle East and North Africa | 4.1 | 0.0 | 8 | 19.0 | 10.5 | 5 |
| South Asia | 40.5 | 0.0 | 583 | 40.8 | 4.0 | 499 |
| Sub Saharan Africa | 51.7 | 2.8 | 252 | 55.5 | 20.3 | 104 |

Source: Authors' estimates

**Table 6.3 Composition of the Global Middle Class**

| Region | 2005 | | 2050 | |
|---|---|---|---|---|
| | **Millions** | **%** | **Millions** | **%** |
| *Developed Countries* | *190.8* | *33.0* | *27.1* | *4.3* |
| *Developing Countries* | *260.2* | *6.4* | *2,117.3* | *29.7* |
| - East Asia and the Pacific | 41.1 | 2.3 | 785.7 | 35.0 |
| - Eastern Europe and Central Asia | 85.9 | 19.7 | 117.9 | 30.5 |
| - Latin America and the Caribbean | 107.5 | 20.3 | 245.9 | 31.8 |
| - Middle East and North Africa | 18.3 | 8.9 | 151.2 | 47.0 |
| - South Asia | 0.6 | < 0.1 | 657.6 | 29.2 |
| - Sub Saharan Africa | 6.8 | 1.3 | 159.1 | 16.6 |
| *Total* | *451.0* | *8.15* | *2,144.3* | *28.4* |

Source: Authors' estimates

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## APPENDIX 1: THE MODEL USED FOR THE CLIMATE CHANGE SIMULATIONS

The quantitative analysis of the climate change section of this paper relies extensively on the World Bank's dynamic global computable general equilibrium model, ENVISAGE (ENVironmental Impact and Sustainability Applied General Equilibrium Model; See van der Mensbrugghe 2009). Underlying the model is the 2004-based Release 7 of the GTAP database that divides the world economy into 113 countries/regions (of which 95 are countries) and 57 commodities (More on the GTAP data can be found at www.gtap.org). For modeling purposes the underlying database is typically aggregated to a more manageable set of regions and sectors with a focused selection of both depending on the objectives of the particular study. In the case of the current study the focus has been on the agriculture and food sectors, but energy as well to capture the emergence of biofuels and the linkage between energy and agriculture. ENVISAGE has been designed for climate change studies and therefore the standard GTAP data is supplemented by several satellite accounts. These satellite accounts include energy data in volume, carbon emissions linked to the burning of fossil fuels, and emissions from the other Kyoto greenhouse gases, i.e. methane ($CH_4$), nitrous oxides ($N_2O$), and the fluorinated gases (F-gases). Both methane and nitrous oxides are linked to agricultural production. The other GHG differ from carbon emissions. First, they have a more exhaustive set of drivers since they can be associated with all intermediate inputs, not simply fossil fuels, as well as factor inputs (for example land in the case methane generated by the production of rice) and output. Second, there exist abatement technologies that are more complex than in the case of fossil fuel-based carbon emissions. With current technologies, the latter can only be abated by either lowering consumption of fossil fuels or substitution into lower- or zero-emission fuels. In the case of the other GHG, abatement technologies may exist that involve different production methods, though presumably at a higher cost.

Separately, we have supplemented the GTAP data with a more exhaustive set of electricity activities—splitting the single GTAP electricity sector into five production activities that include coal fired, oil and gas fired, nuclear, hydro-electric and other (including all existing renewables). For long-term scenario analysis we also introduce several new energy technologies that initially have low penetration, but that under certain circumstances could potentially replace conventional technologies. These new technologies include first and second generation biofuels as potential substitutes in the transport sector, and coal and gas carbon capture and storage (CCS) in the power sector.

In most respects ENVISAGE is a rather classical recursive dynamic global CGE with a time horizon spanning 2004-2100. Production is based on the capital-labor substitution with capital and energy near-complements in the short-term and substitutes in the longer-term. A vintage production structure is employed that allows for partial capital mobility across sectors in the short-term, or a putty-semi-putty technology. Vintage capital is associated with lower production flexibility, whereas new capital is more flexible thus aggregate flexibility depends on the share of vintage capital in total capital, with greater flexibility associated with those economies with the highest savings rate. Factor payments accrue to a single representative household in each region and the latter allocates income between savings and expenditures on goods and services. The model allows for significant flexibility in specifying consumer demand. The top level utility function can be specified using one of three demand systems—constant difference in elasticities (CDE, Hertel, 1997), extended linear expenditure system (ELES, Lluch, 1973), and (AIDADS, Rimmer and Powell, 1996). The top level utility function can be specified at a different commodity aggregation than production. A transition matrix—that allows for commodity substitution—converts consumer goods to produced goods. Energy demand is specified as a single bundle for each agent in the economy. Energy demand is then split into demand for specific types of energy using a nested CES structure. Trade is specified using the ubiquitous Armington assumption (Armington, 1969)—though the model allows for homogeneous commodities as well. Government plays a relatively passive role—collecting taxes and spending on goods and services. The government's fiscal balance is fixed in any given year (and declines towards 0 from its initial position by 2015), and the household direct tax schedule shifts to achieve the fiscal target (The base year imbalance converges towards zero at some later date currently set at 2015.). The latter implies that changes in indirect taxes (e.g. import tariffs or carbon taxes) are recycled in lump-sum fashion to households. Investment is savings driven and savings rates are influenced by the overall growth rate as well as demographic factors such as dependency ratios. The current account balance for each region is fixed in any given. The base year balances converge towards zero at some date (currently set to 2025). An ex ante shift in either import demand or export supply influences the real exchange rate. Thus, for example, if a country is forced to import more food due to climate damages to its agriculture, this would normally entail a real exchange rate depreciation that increases demand for its exports in order to pay for the additional food imports.

ENVISAGE has been developed as an integrated assessment model (IAM). Emissions of the greenhouse gases generated by the economic part of the model lead to changes in atmospheric concentrations. A simple reduced form atmospheric model converts changes in the stock of atmospheric concentrations into changes in radiative forcing and global mean temperature. The resulting changes in global mean temperature feedback on the economy through damage functions that affect various economic drivers. In the current version of the model the only feedback is through changes in agricultural productivity. The agricultural damage functions have been calibrated to the estimates from the recent study by Cline 2007.

Dynamics in ENVISAGE is driven by three key factors. The first is demographics, which describe population and labor force rates of growth. Following a common practice, our baseline uses the medium variant from the UN populations forecast, with the growth of the labor force equated to the growth of the working age population (defined as those between 15 and 65 years of age). The second key driver is formed by savings and investment which jointly determine the overall level of capital stock (along with the rate of depreciation). In ENVISAGE the savings function is partially determined by demographics. Generally speaking, savings will rise as dependency ratios (both under 15 and over 65) fall.

The third driver is productivity. ENVISAGE differentiates productivity across broad sectors: agriculture, energy, manufacturing, and services. Agriculture's productivity growth has two components to be calibrated. On one hand, the exogenous component is calibrated to 2.1 percentage points per year, consistent with recent trends (World Bank, 2008). On the other, the endogenous component comes from a linear damage function which links increases in global temperature to declines in agricultural TFP and is calibrated according to Cline's average estimates with and without carbon fertilization (Cline, 2007).

Productivity in other sectors is unaffected by climate change, and is calibrated through 2015 to match the World Bank's medium- and long-term forecast. After 2015, productivity growth in the US is calibrated to achieve a long-term average (2004-2100) growth in real GDP per capita of 1.2 percent per year—with faster growth in the first half of the century—while productivity in other countries/regions is calibrated based on simple convergence assumptions.

# POVERTY, GROWTH, AND INEQUALITY OVER THE NEXT 50 YEARS

**Evan Hillebrand**[1]

## SUMMARY

Global poverty has fallen dramatically over the last two centuries, and the fall has intensified in recent decades, raising hopes that it could be eliminated within the next 50 years. As industrialization, specialization, and trade raised economic growth and living standards in Western Europe and the European offshoots in the 19th century, much of the rest of the world also started growing rapidly after 1950.

Poverty reduction, however, has been very uneven across countries. Since 1980, China alone accounted for most of the world's decline in extreme poverty. Even though there has been a huge rise in income inequality within China, economic growth has been so strong that hundreds of millions of people have risen out of extreme poverty and the poverty ratio has plummeted. Sub-Saharan Africa, at the other extreme, has seen its poverty headcount continue to rise; the negative impact of low economic growth has far outweighed modest improvements in within-country income inequality.

Strong economic growth is the key to future poverty reduction. If the lagging non-OECD[2] (Organisation for Economic Co-operation and Development) countries are able to transition to a sustainable higher growth path, the global poverty ratio will fall from about 21 percent in 2005 to less than 2.5 percent in 2050 and the number of people living in absolute poverty will decline another billion people. While the historical record is clear that market-friendly policies and competent governance are critical to growth, few economists are bold enough to claim they know the precise combination of policies, and how to implement and sustain those policies, to achieve this economic transition. Forecasts of future economic growth rates and poverty rates are necessarily speculative and depend on a large number of assumptions about human behavior and policy decisions that are impossible to know in advance.

In a less optimistic scenario, I assume that the regions that have been lagging, especially sub-Saharan Africa, do not improve upon their growth rates of the last 25 years. This results in much higher poverty levels—almost 900 million more people living in absolute poverty in 2050 than in the optimistic scenario. I have also considered, but not explored empirically, even more depressing scenarios. Resource constraints, if not met by technological solutions, will surely make the poverty estimates shown here worse. A breakdown of the world capitalist system or even a gradual turning away from the system that has done so much to reduce global poverty over the last two centuries would be disastrous.

## POVERTY MEASUREMENT

Before modern economic growth took off in a few countries in Western Europe, a few European offshoots and Japan—a group of countries hereafter referred to as the OECD—living standards were in all countries very low on average by modern standards. Maddison[3] (2003) estimated OECD gross domestic product

[1] Patterson School of Diplomacy and International Commerce, University of Kentucky, United States of America. This research received support through a grant from the Food and Agriculture Organization of the United Nations for the project entitled How to Feed the World in 2050. Parts of this paper represent a revision and extension of The Global Distribution of Income in 2050, *World Development* 36(5), 2008. The views expressed in this information product are those of the author(s) and do not necessarily reflect the views of the Food and Agriculture Organization of the United Nations.
[2] The author divides countries into two groups: the OECD countries as of 1981 (Austria, Australia, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Luxembourg, Portugal, New Zealand, Netherlands, Norway, Spain, Sweden, Switzerland, United Kingdom and United States of America), and the Non-OECD countries (even though some of the latter group are now part of the OECD).
[3] Maddison actually estimated $1109 and $578 in 1990 purchasing power parity prices but all his figures have been revised in this paper into 2005 prices. See the technical appendix for a brief discussion of purchasing power parity and inequality measures such as the Gini coefficient and the Lorenz curve.

(GDP) per capita in 1820 at about $1571 in 2005 purchasing power parity dollars (PPP) versus $730 on average in the non-OECD countries. Rising economic growth in the OECD countries over the next century raised incomes and cut poverty dramatically, leaving the non-OECD countries far behind. Bourguignon and Morrisson (2002) attempted to combine measures of income distribution within countries with cross-country GDP measures to get a measure of the global distribution of income and a global measure of poverty. Their paper tells a dramatic and straightforward story. Global poverty rates have fallen sharply, from 85.2 percent in 1820 to 31.3 percent in 1980, as economic growth everywhere far outpaced population growth. But they also showed that the global distribution of income became much more unequal. Global inequality was high in 1820 (Gini coefficient of 50.0) and it rose over the next 160 years, reaching 65.8 in 1980. In the early 19th century, most inequality was due to differences within countries, but most of the rise since 1820 has been due to differences in growth rates among countries. Economic growth, per capita, in the OECD countries was twice as fast as in the non-OECD countries, 1820 to 1980. The figures shown in Table 1 below present an introduction to the historical data on growth and poverty, mainly based on the work of Maddison (2001) and Bourguignon and Morrisson (2002), on recently updated work on poverty by Chen and Ravallion (2008), and on long-run poverty forecasts that will be discussed in this paper.

Table 1
**Long Run Estimates of Growth and Poverty**

| | | | | | | Alternative Forecasts | |
|---|---|---|---|---|---|---|---|
| | | | | | | Market Firs | Trend Growth |
| **World** | 1820 | 1950 | 1980 | 1981 | 2005 | 2050 | |
| GDP (billions of 2005 ppp $) | 913 | 7,006 | | 26,825 | 56,593 | 309,569 | 193,318 |
| Population (millions of people) | 1,041 | 2,525 | | 4,511 | 6,458 | 9,301 | 9,301 |
| GDP per capita (2005 ppp $ per year) | 876 | 2,775 | | 5,947 | 8,764 | 33,285 | 20,785 |
| *average annual percent change from previous period* | | | | | | | |
| Absolute Poverty Headcount (millions) | 887 | 1,376 | 1,390 | 1,896 | 1,377 | 245 | 1,120 |
| Absolute Poverty Ratio | 85.2% | 54.5% | 31.3% | 42.0% | 21.3% | 2.6% | 12.0% |
| Inequality Index (Gini coefficient) | 50 | 64 | 65.8 | 70.9 | 68.4 | 64.8 | 67.9 |
| **Non-OECD** | | | | | | | |
| GDP (billions of 2005 ppp $) | 628 | 2,702 | | 11,324 | 26,008 | 189,980 | 112,177 |
| Population (millions of people) | 860 | 1,947 | | 3,744 | 5,561 | 8,310 | 8,310 |
| GDP per capita (2005 ppp $ per year) | 730 | 1,388 | | 3,024 | 4,677 | 22,861 | 13,498 |
| *average annual percent change from previous period* | | *0.5%* | | *2.5%* | *1.8%* | *3.6%* | *2.4%* |
| Absolute Poverty Headcount | | | | 1,896 | 1,377 | 245 | 1,120 |
| Absolute Poverty Ratio (share of Non-OECD population) | | | | 50.6% | 24.8% | 2.9% | 13.5% |
| **OECD** | | | | | | | |
| GDP (billions of 2005 ppp $) | 284 | 4,304 | | 15,501 | 30,585 | 119,589 | 81,142 |
| Population (millions of people) | 181 | 578 | | 767 | 897 | 990 | 990 |
| GDP per capita (2005 ppp $ per year) | 1,571 | 7,446 | | 20,222 | 34,089 | 120,756 | 81,933 |
| *average annual percent change from previous period* | | *1.2%* | | *3.3%* | *2.2%* | *2.9%* | *2.0%* |

Note: the Gini coefficient is calculated on an individual basis: it uses information on within country income distribution.
*Sources: GDP 1981-2005 from World Development Indicators, earlier years linked from Maddison (2001).*
Population, 1981-2005 from World Development Indicators, earlier years linked from Maddison (2001)
Poverty Headcount and Ratios: 1981-2005 from Chen and Ravallion (2008); 1820-1980 from Bourguignon and Morrisson (2002)
Gini coefficients, 1981-2005 are author's calculations; 1820-1980 from Bourguignon and Morrisson.
The forecast numbers will be explained in the text below.

And while the poverty ratio was falling, the number of people living in absolute poverty—measured at the $1.25 a day standard in purchasing power parity dollars[4]--kept growing, from under 900 million in 1820 to almost 1.4 billion in 1980 (Bourguignon and Morrisson, 2002).

Subsequent work by Bhalla (2002), Sala-i-Martin (2002a, 2002b), Chen and Ravallion (2004), and Hillebrand (2008), extended the analysis from 1980 and found a pronounced downward trend in poverty

[4] The new standard is $1.25 a day, measured in 2005 purchasing power parity dollars. Previous measures of absolute poverty were at $1 a day using 1985 price levels and $1.08 using 1993 price levels. While this paper uses $1.25, or $2.50 a day as poverty threshold figures it should be understood that these figures are consistent with earlier literature using the $1 a day standard.

headcounts and poverty ratios, mainly because of very rapid economic growth in China and India. The conclusions on global inequality are more mixed. Bhalla, Sala-i-Martin, and Bourguignon and Morrisson show a downward trend in global income inequality from 1980. Milanovic (2005) and Hillebrand (2008) show little trend, at least until the late 1990s or early 2000s.

Poverty estimates made prior to late 2008 have been thrown into doubt by the release of new purchasing power parity price estimates by the International Comparison Project (2008). This new study is based on a much more complete global survey of prices (and one that includes China for the first time) and presumably gives a much more accurate measure for gauging cross-country differences in income and consumption (Heston, 2008). The major impact of this new work is that price levels for most of the non-OECD economies have been revised upward, meaning that income, production and consumption levels have been revised sharply downward, most importantly for China and India (Table 2).

Table 2
**New and Old Estimates of GDP Per Capita in 2005**
*Dollars in 2005 prices, but based on different estimates of prices*

| | 2005 ICP | 2005 WDI | 2005 PWT63 | 2005 Exchange Rate |
|---|---|---|---|---|
| China | 4,091 | 6,760 | 6,637 | 1,721 |
| India | 2,126 | 3,452 | 3,536 | 707 |
| Japan | 30,290 | 30,736 | 27,726 | 35,604 |
| United States | 41,674 | 41,674 | 41,674 | 41,674 |

*Source:* Heston (2008)
Note: WDI refers to World Development Indicators, the World Bank's data base. PWT63 refers to Penn World Tables, version 63.

A new paper by Chen and Ravallion (2008) makes use of the 2005 ICP purchasing power parities estimates to create new estimates of global poverty, 1981-2005, which are hundreds of millions of people higher than their own previous calculations or the other estimates appearing in the literature[5] (Table 3). The new Chen-Ravallion poverty numbers, while obviously pointing in a direction consistent with the revisions of GDP per capita shown in Table 1, raise numerous questions of their own: has the calculated fall in Chinese poverty[6] really been so dramatic? Heston (2008) asserts that the implied Chinese growth going very far backward is implausible. Has the fall in Indian poverty really been so small compared to Bhalla's calculations? Bhalla (2005) asserts that the household surveys which underpin the Chen-Ravallion poverty estimates badly underestimate total Indian consumption. Why are the implicit aggregate consumption figures for many countries so different from national income account figures? The aggregate consumption share figure falls dramatically in both China and India leading to far higher estimates of poverty than consumption figures from the National Accounts would suggest. Some of these questions may be answered when more details of the ICP 2005 are released and when the Penn World Tables completes its analysis of the data but some will probably linger indefinitely due to disagreements over data and methodology.

[5] The data revision, not changed economic circumstances, account for the huge jump in the estimate of people living in absolute poverty in 1981 as estimated by Chen and Ravallion compared to 1980, and as estimated by Bourguignon and Morrisson. The new price data will presumably cause the 1820-1980 poverty estimates to be revised upward too, but this work has not yet been done.
[6] See Appendix Table 1 for the Chen and Ravallion poverty headcount estimates by country, for 1981 and 2005.

Table 3

**New and Old Poverty Estimates for 2005**

*Millions of people with consumption below $1.25 per day in 2005*

| | Chen/Ravallion 2008 | WDI 2007 | Hillebrand 2008 |
|---|---|---|---|
| China | 208 | 77 | 131 |
| India | 456 | | 163 |
| Sub-Saharan Africa | 391 | | 427 |
| World | 1377 | 977 | 965 |

*Source:* Chen and Ravallion (2008) and Hillebrand (2008). The WDI numbers are World Bank updates of the Chen-Ravallion (2004) calculations for 2001.

In any case, all poverty figures are estimates, based on imperfect data, and on many different, challengeable, assumptions about how to put the data together to come up with the global inequality measures and poverty headcounts. For now, the Chen-Ravallion figures are the most up-to-date and comprehensive estimates available. The poverty numbers in the Chen-Ravallion 2008 paper, and the underlying estimates for 119 countries made available through the World Bank's Povcal website[7], will constitute the starting point for this paper's estimates of poverty through 2050.

## EXPLAINING CHANGES IN POVERTY, 1981-2005

World poverty fell dramatically, 1981-2005, according to estimates by all the sources cited above, including the new Chen-Ravallion work. All sources also agree that most, if not all of the gains, were due to huge decreases in the Chinese poverty headcount. According to Chen and Ravallion the world absolute poverty headcount fell by over 500 million people, 1981 to 2005,[8] and the world poverty headcount ratio fell from 42 percent to 21.3 percent (Table 4). The poverty headcount in China alone, however, fell by over 600 million. In only 24 years China went from 84 percent of its people living below the $1.25 a day absolute poverty level to having less than 17 percent of its people so impoverished. Some other large countries (Brazil, India, Indonesia, Mexico, Pakistan, South Africa and Vietnam) also showed dramatic reductions in the poverty ratio, and, sometimes the poverty headcount as well (the data for all 119 countries in the World Bank database are shown in Appendix Table 1).

[7] http://web.worldbank.org/WBSITE/EXTERNAL/EXTDEC/EXTRESEARCH/EXTPROGRAMS/EXTPOVRES/EXTPOVCALNET/0,,contentMDK:21867101~pagePK:64168427~piPK:64168435~theSitePK:5280443,00.html

[8] All historical poverty figures from this point forward in the paper will be taken from Chen and Ravallion (2008) or from the World Bank's Povcal website which contains more details than included in the 2008 paper.

Table 4
**World Poverty Headcounts and Poverty Ratios, 1981 and 2005**

| | 1981 | 2005 | 1981 | 2005 |
|---|---|---|---|---|
| | Poverty Headcount (millions) | | Poverty Headcount Ratios | |
| World | 1896 | 1377 | 42.0% | 21.3% |
| East Asia | 1072 | 316 | 77.7% | 16.8% |
| China | 835 | 208 | 84.0% | 15.9% |
| Indonesia | 108 | 47 | 71.5% | 21.4% |
| Vietnam | 49 | 19 | 90.4% | 22.8% |
| South Asia | 548 | 596 | 59.4% | 40.3% |
| India | 421 | 456 | 59.8% | 41.7% |
| Pakistan | 62 | 35 | 72.9% | 22.6% |
| Latin America | 42 | 46 | 11.5% | 8.4% |
| Brazil | 21 | 14 | 17.1% | 8% |
| Mexico | 6.8 | 2 | 9.8% | 1.7% |
| Sub-Saharan Africa | 214 | 391 | 53.7% | 51.2% |
| Congo, DR | 9 | 35 | 31.9% | 59.2% |
| Nigeria | 35 | 88 | 47.2% | 62.4% |
| Republic of South Afirca | 10 | 10 | 34.9% | 20.6% |
| East Europe and Central Asia | 7 | 17 | 1.7% | 3.7% |
| Middle East/North Africa | 14 | 11 | 7.9% | 3.6% |

*Source:* Chen and Ravallion (2008), except that I divide the world headcount by world population.

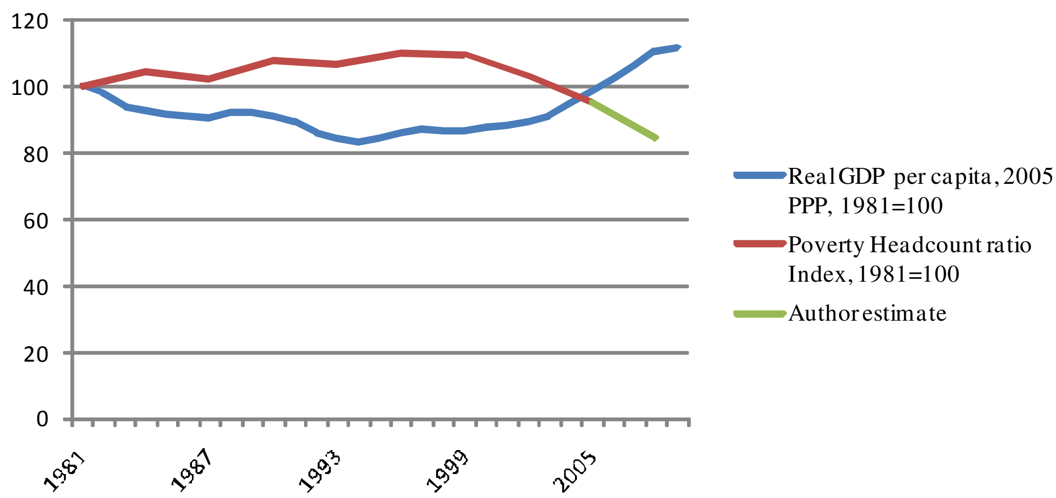
Sub-Saharan Africa, on the other hand, saw a huge increase in the number of people living in absolute poverty and only a small decrease in the poverty ratio. Only four (out of 42) sub-Saharan African countries (Cape Verde, Mauritania, Senegal and South Africa) recorded a fall in poverty headcounts, while a dozen African countries recorded increases in poverty headcount ratios and a few countries (the Democratic Republic of the Congo, Nigeria and the United Republic of Tanzania) showed tens of millions more people living in absolute poverty in 2005 than in 1981. Faster economic growth in the last decade, though, has led to a slight decline in the Sub-Saharan Africa poverty ratios since 1996 (Figure 1).

Changes in the poverty headcount of any country can be ascribed to one of three factors: aggregate per capita economic growth, changes in the share of aggregate gross domestic product (GDP) going to private consumption versus the other components of GDP[9], and distribution of consumption among individuals within each country.[10] For example, if the share of GDP going to consumption remained the same in 2005 as in 1981, and the distribution shares across the population remained the same, all the differences in poverty levels could be explained by changes in economic growth.

[9] Investment, government consumption, and net exports.
[10] Measured by estimated Lorenz curves and the SAP methodology.

Figure 1

**Sub-Saharan Africa: Trends in GDP per capita and the Poverty Headcount Ratio**




*Source:* Poverty Headcount ratio from Chen and Ravallion (2008). Estimate of 2008 by author. GDP per capita from WDI database

Economic growth in the non-OECD countries over-determines the estimated fall in poverty headcounts (Table 4). Had Lorenz curves and consumption ratios remained constant the world poverty headcount would have fallen from 1896 million people in 1981 to 791million in 2005, not the actual figure of 1377 million estimated by Chen and Ravallion. Declines in the aggregate consumption ratio and shifts in distribution combined to increase the poverty headcount by almost 600 million people from what it would have been if aggregate and by-person distribution had remained at 1981 levels.

Even though China started with an extremely high rate of absolute poverty, its rate of real per capita economic growth was so high (8.8 percent a year[11]) that even the estimated consumption of the lowest 10 percent of the population would by 2005 have far surpassed the $1.25 a day per person absolute poverty standard had not the overall amount of GDP going to consumption dropped sharply and the inequality of distribution of that total amount of consumption increased sharply.[12] Poverty headcounts were down in most other East Asian countries as well. Indonesia and Vietnam cut their poverty headcounts sharply by combining strong economic growth without adversely affecting consumption ratios. The Philippines was the worst performer in the East Asian region: the poverty headcount went up 3.7 million people, mainly because of low economic growth.

India had high economic growth, 3.3 percent per year, fast enough to raise 364 million people out of absolute poverty had not the distribution of income and consumption changed so greatly. But the ratio of aggregate consumption to GDP fell by about 20 percentage points over this period, and aggregate consumption was distributed more unevenly, with the overall Gini coefficient on household consumption rising about 4 percentage points. Pakistan performed better than India. Its poverty headcount went down and its poverty ratio dropped dramatically, from 72.9 percent to 22.6 percent, according to the Chen-Ravallion numbers. Its economic growth was weaker than India's, but it did not have the dramatic decline in the ratio of private consumption to GDP.

[11] 1982-2005, see World Development Indicators data base, 2009, using GDP per capita in 2005 ppp $.
[12] The World Income Inequality Database suggests that aggregate Chinese Gini coefficient rose about 15 points, from 29 to 44 over this period, while the Indian Gini coefficient rose about 4 points, from 32 to 36 (http://www.wider.unu.edu/research/Database/en_GB/database/).

Table 5
**Impact of Economic Growth and Distribution Shifts on Poverty Head Counts**
*millions of people*

| | 1981 | 2005 | Total Change | Change due to GDP Growth | Change due to Shifts in Aggregate Consumption Ratio | Change due to Income Distribution Shifts (shifts in lorenz curves) |
|---|---|---|---|---|---|---|
| World | 1896 | 1377 | -520 | -1105 | 344 | 241 |
| East Asia | 1072 | 316 | -755 | -957 | 21 | 181 |
| of which China | 835 | 208 | -627 | -835 | 38 | 170 |
| South Asia | 548 | 596 | 47 | -389 | 362 | 75 |
| of which India | 421 | 456 | 35 | -364 | 324 | 75 |
| Sub-Saharan Africa | 214 | 391 | 177 | 252 | -63 | -11 |
| Latin America and Caribbean | 41 | 44 | 3 | -3 | 21 | -15 |

*Source:* The 1981 and 2005 poverty headcounts are from Chen and Ravallion.
Growth and distribution shifts are estimated by the author. (sums may not total due to rounding)

Sub-Saharan Africa had very negative results. Average real GDP growth was slower than population growth and would—without favorable distributional changes—have caused poverty headcounts to double. The worst performers were Côte d'Ivoire and Democratic Republic of the Congo. These two conflict-torn countries had average negative GDP per capita growth of 2 percent and 4 percent per year, respectively. The ratio of consumption to GDP soared but not enough to compensate for the growth effects. Nigeria also had very negative results, with the poverty headcount rising almost 54 million people and the poverty ratio rising from 18 to 62.4 percent. Nigeria had a toxic combination of low GDP per capita (0.7 percent per year), a sharp fall in the ratio of private consumption to GDP (from 42 to 28 percent) and a rise in consumption inequality (the Gini coefficient rose from 38.7 to 42.9). The Republic of South Africa was one of the best performers on the continent. It had low economic growth (-0.2 percent), but a large increase in the consumption ratio (from 43 to 53 percent), and a slight decrease in inequality (the Gini coefficient fell from 59 to 58).

Latin America has higher average incomes and less absolute poverty than Asia and sub-Saharan Africa. Because it didn't have much absolute poverty to begin with in 1981 it did not take much per capita GDP growth to push more people above the poverty threshold as long as distribution did not change adversely. Per capita real GDP growth was only 0.7 percent per year, 1981-2005, but the regional consumption ratio average rose two percentage points, and the population-weighted regional Gini coefficient rose only slightly. Mexico and Brazil have made dramatic progress from 1981. Brazil has brought its poverty headcount down by almost 7 million people and its poverty ratio has shrunk from 17 percent in 1981 to 7.8 percent in 2005. Mexico has reduced its poverty headcount by 4.9 million people while shrinking its poverty ratio from 9.8 percent in 1981 to 1.7 percent in 2005. Argentina, Bolivia, Peru, and Venezuela all saw sharp increases in their poverty ratios between 1981 and 2002, but both the headcount and the poverty ratio showed a large decrease between 2002 and 2005, according to the Povcal database.

## Trends in global inequality, 1981-2005

Chen and Ravallion do not report any calculations of global inequality. In my 2008 paper I report several different estimates of global inequality (Table 6). Most of these (Milanovic is the exception) use estimates of within-country income or consumption distributions and multiply those distribution times the value of income or consumption taken from the national income accounts. Milanovic would say that a better measure would be to distribute the total consumption by country inferred from the household consumption surveys. I have taken the data for the 119 countries included in the Povcal database and added consumption figures for the additional 63 countries covered in my database from various sources (but mostly using aggregate consumption data in 2005 purchasing power parity terms) and used Bhalla's standard accounting procedure (SAP) to calculate world Gini coefficients which fell slightly 1981-2005, mainly because of strong economic growth in Asia.[13]

[13] Using the 2005 ICP Milanovic (2008) has also revised upward his estimate of global inequality. His new estimate for the global Gini coefficient in 2002 is 69.9 compared to his previous estimate of 65.3. See the technical appendix for details on the SAP.

Table 6
**World Gini Estimates**

| | 1820 | 1970 | 1980 | 1981 | 1988 | 1992 | 1993 | 1998 | 2005 |
|---|---|---|---|---|---|---|---|---|---|
| Bourguignon/Morrisson | 0.50 | 0.65 | 0.657 | | | 0.657 | | | |
| Bhalla | | | 0.686 | | | 0.678 | | 0.654 | |
| Sala-i-Martin | | | 0.662 | | | 0.645 | | 0.633 | |
| Milanovic | | | | | 0.619 | | 0.652 | 0.642 | |
| Hillebrand | | | 0.653 | | | | | | 0.634 |
| 2009 estimate using 2005 ICP data | | | | 0.709 | | | | | 0.684 |

*Sources:* Bourguignon and Morrisson (2002), Bhalla (2002), Sala-i-Martin (2002b), Milanovic (2005), Hillebrand (2008) and new estimates by author.

## FORECASTING ECONOMIC GROWTH

Forecasting poverty 40 years in the future is mostly a matter of forecasting economic growth. Bourguignon and Morrisson claimed that economic growth had by far the greatest impact on global poverty inequality, 1820-1992. We know from Ravallion (2001) and Dollar and Kray (2002) found that the poor on average tend to share proportionately in the gains from economic growth. And we have seen in the above analysis of the Chen-Ravallion poverty data set that economic growth far outweighed the impact of the other two proximate causes: the distribution of national output between consumption and other uses, and changes of distribution by person in each country.

Economists have long relied on the neoclassical growth model (Solow, 1956) to think about economic growth. Economic growth, in Solow's framework, depends on changes in the capital stock (machinery, buildings, roads, communication lines, etc.), changes in the labor force, and changes in technology. In this model diminishing returns eventually set in and growth slows unless technological change intervenes to keep productivity increasing.

Changes in technology, according to empirical research by Abramowitz (1956) and many others, have contributed the major part of long-run economic growth in the OECD countries, and thus should be important to forecasts of the future. While changes in capital and labor are relatively simple to model and forecast, however, technology is not. Solow treated the technological change component as a residual or exogenous factor, not explainable by growth theory. Later researchers, especially Romer (1987, 1990), Grossman and Helpman (1991), and Barro and Sala-i-Martin (1995) have attempted to "endogenize" growth theory by trying to explain theoretically (and demonstrate empirically) the causal forces underlying technological progress, especially investment in research and development, but also institutional factors such as protection of property rights, regulation of international trade, and taxation.

An important corollary of the extended neoclassical growth model for poverty analysis is the convergence concept. It is implicit in the neoclassical growth model that poor countries should grow faster than rich countries and should eventually catch up—converge—in per capita output and income. According to Barro (1998, p 1): "If all economies were intrinsically the same except for their starting capital intensities, … poor places would tend to grow faster per capita than rich ones." Because rich countries are limited by diminishing returns and poor countries can grow faster by increasing capital stocks and adopting best-practice technology, incomes ought to eventually converge. Lucas (2000) makes use of this convergence concept to predict rapid non-OECD growth and a convergence of incomes by 2100.

Douglas North (2005), on the other hand, believes that neo-classical economic theory by itself is not much help in explaining the process of economic change—institutions are more important. Economies are composed of institutions that provide incentives for work, trade, saving, and investment—or not. Institutions that stifle competition and encourage predation might well arise and persist, contra to the convergence hypothesis, because institutions poorly designed for economic growth might be admirably suited for maintaining the power and prosperity for those in command or might be based on cultural beliefs that do not value economic growth highly. Paul Collier (2007) warns us that bad governance is only one of the four poverty traps that can keep countries down[14]. Mancur Olson (1982) suggests that even rich and prosperous countries, which achieved prosperity through good institutions, are constantly at risk of economic sclerosis as special interests accrue power over time through lobbying and politics to undermine the institutions that spur competition and investment.

Most long run economic growth forecasts that appear in the literature are based on modeling exercises that use neoclassical and endogenous growth theory, the convergence concept, and some reference to the institutional ideas of North and Olson and others. While there is much to criticize and debate in the theoretical literature, it is also important to note that the empirical estimates of the underlying relationships are also contentious, with the magnitude of the relationships and even the direction of causality often in dispute. Any forecasting effort also requires many assumptions about policy choices by future governments over long periods of time; long-run forecasting efforts are necessarily speculative.

## Forecasting Poverty and Inequality

What will global poverty look like in 10 or 20 or 45 years? Not many explicit forecasts appear in the literature. Chen and Ravallion (2004, p. 33) using the old ICP data suggest it will drop, but their estimate is based on two time series regressions (one for East Asia, one for South Asia) based on past changes in the poverty headcount relative to assumptions about long-term economic growth. They assume that the poverty ratio in Africa will continue to be 45 percent. Their modeling and assumptions add up to a world poverty rate of 15 percent in 2015, thus meeting the Millennium Development Goals.

Bhalla (2005) concluded that the world poverty rate has already gone below 15 percent and will continue to go lower. Bhalla estimated a reduced-form equation to calculate the elasticity of the poverty headcount ratio to growth in incomes or consumption and then used this regression model to forecast future poverty levels assuming the distribution of income or consumption within countries remains the same.

The World Bank has been making forecasts of the 2015 world poverty rate in its *Global Economic Prospects* series since 2001. In the latest edition (2009) the 2015 forecast is revised upward from 10.2 percent to 15.5 percent because of the ICP revisions. These forecasts apparently use a cross-country regression that posits a constant elasticity of poverty reduction to per capita income growth adjusted by estimates of changes of within-country inequality. The constant elasticity assumption is not very reliable for extending projections very far in the future given that we are talking about movements below or above a fixed poverty threshold. A country with incomes just below the threshold can cross the threshold with only a low level of growth and a country with incomes far below the threshold can have high rates of growth without moving many people out of extreme poverty. A different forecasting methodology is clearly needed.

Hughes and his colleagues (2008) in a major new study review past poverty forecasting efforts in detail and present their own set of forecasts to the year 2055 using the "lognormal" distribution to convert estimates of average income and the Gini coefficient into poverty headcounts. This methodology has the advantage of embedding the poverty estimates directly into a long range macroeconomic simulation model (the International Futures Model[15]) so the authors of the paper or any user of the model can directly test not only the impact of alternative assumptions about economic growth on poverty futures, but also simulate the effects of changes in a wide variety of policy levers on economic growth and hence on poverty. The Hughes estimates are based on the old ICP data and so are not directly comparable to the new Chen-Ravallion numbers that form the basis of this study.

This paper uses an alternative methodology. If we have estimates of future GDP, if we assume the within-country distribution of income and consumption remains constant, and if we assume the ratio of consumption to income is constant, we can simply read off the percentiles of income and consumption using the same accounting framework we did in the historical analysis. All three of these key "ifs" are problematic. There is no scientifically sound methodology to forecast global incomes and consumption decades in the future. Most long-term projections, including this one, rely on scenarios. The researcher posits a set of assumptions about the key drivers of growth, uses a model that relates these factors to economic outcomes, and produces

[14] The others are (1) conflict and political violence, (2) abundance of natural resource wealth that distorts economic growth and (3) geographical disadvantages such as being landlocked, poor in resources or harried by bad neighbors.
[15] See Hughes and Hillebrand (2006).

projections that are presumed to be part of a range of plausible outcomes. The assumption of unchanging within-country distribution is also one that is often made in long-run forecasts (see Chen and Ravallion, 2004a), mainly because there is little scientific basis for predicting long-range changes and the existing empirical work on the subject shows such divergent results (see World Bank (2007) versus Higgins-Williamson (2002)). Consumption-to-GDP ratios could also change for endogenous economic reasons or because of political decisions, but are assumed in this paper to remain constant.

The World Bank poverty estimates tell a good-news story about global poverty from 1981 to 2005, but it is likely that the very high economic growth recorded by the non-OECD drove poverty headcounts down further through 2008. Using actual GDP growth rates between 2005 and 2008 and assuming no changes in within-country distributions, I estimate the global poverty headcount fell over 200 million and the poverty headcount ratio declined to about 18 percent (Table 7).

Table 7
**Poverty Estimates for 2008**

| | 2005 | | 2008 | | 2006-2008 |
|---|---|---|---|---|---|
| | Poverty Headcount | Poverty Ratio | Poverty Headcount | Poverty Ratio | Average annual growth in real *per capita* GDP |
| Non-OECD | 1,377 | 21.3% | 1,132 | 17.6% | 4.6% |
| East Asia | 316 | 16.8% | 247.2 | 15.9% | 5.7% |
| China | 208 | 15.9% | 148 | 12.3% | 7.5% |
| South Asia | 596 | 40.3% | 467 | 30.2% | 4.4% |
| India | 456 | 41.7% | 339 | 29.9% | 4.9% |
| Latin America and Caribbean | 46 | 8.4% | 36 | 6.6% | 3.0% |
| Sub-Saharan Africa | 391 | 51.2% | 352 | 44.3% | 2.9% |

*Source:* 2005 Poverty estimates from Chen and Ravallion (2008); 2006-2008 growth rates from WDI and The Economist magazine. 2008 Poverty estimates are author's calculations based on SAP methodology but adjusted upward based on the World Bank's estimate of the impact of rising commodity prices on the poor. (World Bank, 2009, pg 117)

The analysis relies on the SAP methodology described above and a spreadsheet model that estimates average consumption by percentile of population for 182 countries. The poverty and inequality estimates from the SAP model are driven by population and economic growth numbers that are derived from scenarios produced with the International Futures (IFs) model. The IFs model is convenient because it contains detailed growth models for 182 states, contains numerous policy levers that have been calibrated based on recent empirical work at the World Bank and elsewhere, and because the model already contains numerous well thought-out long range growth scenarios. It will become clear that slightly varying assumptions about a small number of key parameters can have very large effects on global poverty and inequality. The poverty forecasts presented below will be based on two scenarios. The Market First scenario will assume rapid technological change in the OECD countries, a strong tendency toward convergence in the non-OECD countries based on globalization, pro-growth policies, and institutional change. The Trend Growth scenario will assume less technological change, less globalization, and less improvement in economic governance in the slow-growth regions.

## THE "MARKET FIRST" SCENARIO

The "Market First" scenario is based on the IFs default scenario as of October, 2008. It was compiled by the IFs team at the University of Denver using an optimistic set of assumptions consistent with global analysis from the United Nations and the National Intelligence Council.[16] The World Bank elaborated a similar scenario in its Global Economic Prospects: Managing the Next Wave of Globalization (2007). As in the World Bank work, the numbers used here are not a forecast but a scenario based on assumptions about changes in population, capital stock, and productivity gains. High growth is based on assumptions of strong technological change brought about in the OECD countries by continuing research and development. The non-OECD countries advance by catch-up economic growth fostered by high investment, improved governance, efficiencies gained from expanded trade and financial linkages, and rising investment in human

[16] See, in particular, National Intelligence Council (2004, 2008), United Nations (2004), and UNEP (2007).

capital. There is clearly much scope for catch-up growth in the non-OECD countries, but there is also no scientific way of forecasting how much convergence will be achieved or what growth-enhancing or growth-retarding policies will be followed in each country.

The assumptions used here produce another golden age of growth, with world growth and growth in most regions higher than in the last 25 years. With economic growth at this high pitch, world poverty shrinks dramatically. The number of extreme poor shrinks from 1377 million in 2005 (the Chen-Ravallion starting-point number) to 964 in 2015 and 245 in 2050 (Table 8). Strong economic growth leads to the eradication of extreme poverty in India, but not China. China's much more unequal distribution of income and consumption put that country at a disadvantage in eliminating poverty. Sub-Saharan Africa cuts its poverty rate substantially, but, assuming continuing high population growth rates,[17] the number of people living in extreme poverty continues to grow past 2015. A few countries in East and South Asia (Afghanistan, Bangladesh, Nepal, Pakistan, and Democratic People's Republic of Korea) and Haiti account for most of the rest of the people still living in extreme poverty in 2015. By 2050, assuming per capita income growth over 2 percent a year, the poverty headcount in sub-Saharan Africa has started to fall but it still nearly 200 million people. By 2050, in this high growth scenario, the global poverty rate is only 2.5 percent.

Table 8
**Poverty Estimates in the Market First Scenario**

| | *Average annual rate of growth, real GDP per capita* | Poverty Headcount at $1.25 a day | | | Poverty Ratios | | |
|---|---|---|---|---|---|---|---|
| | | Constant within-country distributions | | | | | |
| | 2006-50 | 2005 | 2015 | 2050 | 2005 | 2015 | 2050 |
| World | 3.0 | 1377 | 964 | 245 | 21.3% | 13.3% | 2.6% |
| OECD | 2.8 | | | | | | |
| Non-OECD | 3.8 | 1377 | 964 | 245 | 24.8% | 15.3% | 2.9% |
| East Asia, Pacific | 4.3 | 316.2 | 125.5 | 15.6 | 16.8% | 5.3% | 0.7% |
| China | 4.8 | 207 | 106.1 | 12.4 | 15.9% | 7.6% | 0.8% |
| South Asia | 4.3 | 595.6 | 249.2 | 14.1 | 40.3% | 15.4% | 0.6% |
| India | 3.9 | 456 | 243.2 | 0 | 42.0% | 19.8% | 0.0% |
| Sub-Saharan Africa | 2.5 | 391 | 395 | 205 | 50.9% | 41.1% | 11.7% |
| Latin America | 3.4 | 46 | 35 | 7.8 | 8.2% | 5.6% | 1.0% |
| Middle East/North Afric | 3.3 | 11.0 | 8.7 | 0.7 | 3.6% | 2.2% | 0.1% |
| Eastern Europe/former S | 3.4 | 17.3 | 13.5 | 2.1 | 3.7% | 3.8% | 0.4% |
| | | | | | | | |
| World Gini | | 68.4 | 68.0 | 64.8 | | | |

*Sources: Historical data from World Development Indicators (with estimates from Maddison (2003) for missing data).*
Scenario data from simulations with the International Futures Model

The world Gini coefficient falls to 64.8 in 2050, but still remains high compared to most within-country distributions because economic growth is assumed to continue to be strong in the OECD and other rich countries. Continued high global inequality and high Gini coefficients within many countries are troublesome features even in this low-poverty scenario and may prevent it from happening. Alessina and Perotti (1993) found that income inequality hurts growth by increasing political instability and thereby decreasing investment. Henry Rowan (1995) believes that inequality heightens class conflict, produces capital flight, and encourages redistributive policies that can be self-defeating. Amy Chua (2004) believes that global inequalities provoke resentment of the poor toward the rich countries, inhibiting cooperation and trade at best, and provoking violence at worst.

Sub-Saharan Africa performs relatively poorly in the Market First scenario, but even there the poverty headcount eventually starts to decline. Economic growth in this scenario is not low by world historical standards and good by Africa standards—GDP per capita is projected to rise by 2.5 percent per year for the region. The average of country growth rates is similar, but the IFs projections show a wide range of country growth rates[18]—from -0.8 percent per year in Togo to 5.9 percent per year in the United Republic of

[17] The population growth rates embedded in the IFs forecasts closely track the United Nations' mid-range population forecast.
[18] Mainly because of different assumptions about policy changes by country, and between-country historical differences in translating policy changes into economic growth.

Tanzania. These rates of growth are enough to bring the poverty rate down sharply in the region, but population growth is so high and the starting level of income is so low in most countries that it takes a GDP per capita growth rate of approximately 2 percent per year or more to bring the poverty headcount down. Cameroon, Democratic Republic of the Congo and Liberia are among the weakest performers, and 8 out of 38 countries projected show higher poverty headcounts in 2050 than in 2005. High projected economic growth in Ethiopia, Mozambique, Nigeria and the United Republic of Tanzania accounts for about 70 percent of the fall in the regional poverty headcount. South Africa nearly succeeds in eliminating extreme poverty not because of high economic growth but because it had such a low poverty headcount ratio in 2005 that it did not require much positive per capita economic growth to push almost all of the population above the poverty threshold.

The IFs model also produces estimates of food supply and demand, by country, consistent with its demographic and economic projections. World food demand in this high-economic, medium-population growth scenario increases by about 1.3 percent a year to 2050. World supply rises somewhat less because substantial improvements in technology and transportation infrastructure are assumed to cut crop losses sharply. Land devoted to crop production is assumed to rise only slightly while technological advances increase world average crop yields by about 0.9 percent per year (Table 9). Calories available per person rise everywhere and particularly so in sub-Saharan Africa. If alternative assumptions were made reducing technological advances that aid food production, the relative price of foodstuffs would increase, some countries would be advantaged and some disadvantaged but overall world economic growth would slow and poverty would increase.[19]

Table 9

**World Food Supply and Demand in Market First Scenario**

| | World Crop Production million metric tons | Crop Land million hectares | Yield tons per hectare | Crop Loss Ratio percent |
|---|---|---|---|---|
| 2005 | 4190 | 1544 | 2.71 | 30.3% |
| 2050 | 6584 | 1617 | 4.07 | 22.3% |
| *percent change* | 57.1% | 4.7% | 50.0% | |
| *avg. ann. Pct. Change* | 1.0% | 0.1% | 0.9% | |
| | Calories available per person | | | |
| | World | OECD | Non-OECD | Sub-Saharan Africa |
| 2005 | 2,800 | 3,421 | 2,662 | 2,256 |
| 2050 | 3,207 | 3,635 | 3,135 | 2,588 |
| *percent change* | 14.5% | 6.3% | 17.8% | 14.7% |
| *avg. ann. Pct. Change* | 0.3% | 0.1% | 0.4% | 0.3% |
| | Percent of population malnourished | | | |
| | World | OECD | Non-OECD | Sub-Saharan Africa |
| 2005 | 12.4% | 1.9% | 14.8% | 30.7% |
| 2050 | 4.5% | 0.0% | 5.3% | 18.5% |

*Source:* Market First scenario, International Futures Model

## How might distribution shifts affect future poverty headcounts?

We have seen that economic growth is not the only factor that matters for changes in poverty levels; shifts in the amount of production made available for consumption (shifts in the Consumption/GDP ratio) and shifts in the distribution of consumption among a population (Lorenz curve shifts) also can have large impacts on poverty.

### *Lorenz curve shifts*

Kuznets (1955) suggested that economic development itself made income distributions more unequal, by increasing returns to capital and leaving the rural poor lagging further behind workers in the modernizing

[19] More interactions between growth, inequality, and food supply and demand could be generated for a second iteration of this paper.

sectors of the economy. Recent work by Ravallion (2001) and Dollar and Kray (2002) rebut the idea that growth has negative or any systematic effects at all on distribution. Barro (2000), however, suggests that income inequality does tend to rise until a per capita income of $4,815 (in 2000 PPP dollars) and then starts to fall.[20]

Some researchers have attempted to forecast changes in within-country income distributions based on demographic shifts. Using data from the 1960s through the 1990s, Higgins and Williamson (2002) find a strong relationship between trends in income equality and demographic shifts: inequality decreases as the higher-earning middle-age cohorts grow in proportion to the rest of the population. They forecast very large decreases in within-country inequality over the next 50 years, with the weighted average African Gini coefficient falling from 46.4 in the 1990s to 37.8 in 2050, and the Latin American and Pacific Rim region experiencing similar proportionate declines. Higgins and Williamson also report estimated changes in the ratio of income of the highest to the lowest quintiles (Q5/Q1) for the three regions.

While the Higgins/Williamson regional income distribution estimates do not give a clear linkage to the country income and consumption distributions used in this paper, I used their forecast of the declines in Gini coefficient and Q5/Q1 ratios to generate forecasts of country distributions and then calculated the resulting headcounts to show the sensitivity of the poverty and Gini coefficent numbers to the Higgins/Williamson forecast. The new country-distribution estimates used in this simulation captured the essence of the Higgins-Williamson estimates: the three regional Gini coefficients fell by the same ratio and the change in the Q5/Q1 ratios fell by the same amounts. The postulated change in within-country inequality, motivated by shifting demographics, reduces the global poverty headcount estimate in 2050 from 232 million people to 114 people.

Researchers at the World Bank (2007), however, have recently used other empirical work suggesting a conclusion opposite to the Higgins-Williamson work: as the shares of older workers rise in proportion to the total work force, inequality rises "since wage dispersion within these groups tends to be high":[21] The World Bank suggests an increase of about 4.0 in the African regional Gini coefficient by 2030, and an increase of 1.6 in the Asian Gini coefficient. I generated rough estimates of what the World Bank numbers would mean to the percentile distributions used in this paper; the inferred Q5/Q1 ratios rising in Asia and Africa, instead of falling as in the Higgins-Williamson case. The shifting within-country distribution pushes up the 2050 global poverty headcounts to 328 million people.

Thus the two conflicting views of the endogenous future of Lorenz curve shifts put a band of about a 100 million people on either side of our Market First scenario projected poverty headcount of 245 million in 2050. Of course policy measures—either explicit or unintentional— might also be undertaken by governments that shift the Lorenz curve in either direction.

### *Shifting Consumption/GDP ratios*

Consumption to GDP ratios average about 56 percent in the OECD, and fluctuated around a narrow range, 1981-2005. The average consumption to GDP ratio for the non-OECD countries is similar, but much more variable. The numbers range from 14 to 171 percent of GDP using PPP data from the World Bank's World Development Indicators (WDI) database. Using implicit consumption figures from the household surveys as reported on the Povcal website and dividing by the GDP figures from WDI, the range is even greater, from 7 to 237 percent. Some very large ratios occur in war-torn countries where investment is probably very low and foreign aid is very high. Some very small ratios occur in countries with substantial mineral export wealth. It is also possible that some of the large and small numbers are due to data errors, either in the household surveys or in the National Income Accounts data, or both.

We know from the analysis shown in Table 5 that the poverty estimates were significantly affected by past shifts in the consumption-to-GDP ratios, particularly by the huge implicit decline in the Indian consumption figures. In a long-run scenario such as this with very high growth rates over time one could plausibly assume that the non-OECD consumption rates ought to converge and stabilize near the present OECD levels. Such an experiment was not conducted for this paper but it would probably not have had a great impact on the

[20] This idea could be explored empirically in another iteration of this paper.
[21] Global Economic Prospects (2007, p. 85).

overall numbers—since the starting point for the non-OECD countries was not to dissimilar from the OECD— but it could dramatically affect those countries now far from the OECD average.

This analysis further suggests, however, that the conventional concept of pro-poor growth which looks at just the shift in income Lorenz curves and economic growth (see Kakwani (2000) and Chen and Ravallion (2001) is inadequate—shifts in the consumption ratio must also be considered and should not be treated as independent of either growth or the Lorenz curve. An increase in the consumption ratio, other things equal, reduces the poverty headcount. But if an increase in the ratio comes at the expense of productive investment, the long term effect could be anti-poor.

Our poverty measures rely on household consumption surveys that reflect changes in aggregate consumption figures with little correlation to changes in consumption and GDP figures in the National Income Accounts. This use of sometimes inconsistent data weakens an important analytical link between poverty and economic growth. For example, according to the National Income Accounts data (as converted into 2005 PPP data by the World Bank), India's real GDP per capita grew at an average annual rate of 3.8 percent, 1981-2005, and private consumption per capita grew at 2.9 percent per year. The Povcal database per capita consumption figures, based on the household survey data, grew at just 1.0 percent per year over this period. If Chen and Ravallion are correct in stating that the household surveys are a better measure of consumption than the National Income Accounts, one should probably conclude that the GDP growth estimates are not reliable. More detailed analysis is required illuminating the forces not just behind shifts in the Lorenz curve but also the connection between consumption measured by the household surveys and economic growth.

Setting aside these analytical problems, the numbers in the Market First scenario tell a good-news story. The extreme poverty headcount is shrinking in most regions by 2015 and in all regions by 2050. The original Millennium Development global poverty headcount ratio—15 percent by 2015—should be reached easily.[22] While I have focused on the numbers at the $1.25-a-day standard, the improvements at the more generous $2.50-a-day standard are even more impressive, from 3,085 million (48 percent of world population) in 2005 to 710 million (7.3 percent). Even in the pessimistic scenario in which demographic shifts lead to worsening within-country distributions (the World Bank scenario), the global poverty headcount still shrinks dramatically because of good economic growth.

The trouble with this good-news story, however, is that it is just a scenario; there is no way of knowing if world economic growth rates will be anywhere near this high or how within-country distributions will change. The growth rates assumed in the Market First scenario are, after all, almost everywhere higher than those that actually occurred in the post World War II "golden age" period of global growth when so much of the poverty rate reductions calculated by Bourguignon and Morrisson occurred.

Economic growth above 3 percent per year in real per capita terms in the non-OECD countries is certainly possible over the next 40 years. Most of the countries in this group are so far behind the OECD countries in productivity levels that they have enormous growth potential by adopting modern techniques and gradually converging toward OECD-level productivity. The long-term growth rates envisioned in the Market First scenario for Africa, Latin America, and the Middle East are actually quite close to the growth rates achieved in 2002-2007, coinciding with an unusually high period of world economic growth. But even assuming that war, resource constraints, or climate difficulties do not intrude, maintaining such high growth rates will involve enormous changes in governance, institutions, and attitudes in many countries.

### *Comparison to other long-range growth and poverty projections.*

Nobel-Prize winning economist Robert Lucas (2000) has produced a similar scenario. He believes that the non-OECD countries will converge with the OECD countries over the course of this century, citing three major reasons:

- based on Tamura's work (1996) he assumes technology diffusion, the idea that knowledge produced anywhere benefits producers everywhere;

[22] Chen and Ravallion (2008) suggest that since the original goal was a "halving of the extreme poverty ratio from 1990 to 2015" the upward revision of the historical numbers implies the new goal should be closer to 20% than 15%. That goal is also easily reached in the Market First scenario.

- from Prescott and Parente (1994) he expects improvements in governance ("governments in the unsuccessful economies can adopt the institutions and policies of the successful"); and
- diminishing returns and flows of resources ("high wages in the successful economies lead to capital flows to the unsuccessful economies, increasing their income levels").

Lucas' world growth model suggests that the long period of rising global income inequality that began with the industrial revolution in 1800, slowed down or ended in recent decades, and will reverse itself in this century: "I think the restoration of inter-society income equality will be one of the major economic events of the century to come."[23]

Henry Rowan (1996) predicted that within a generation most of the world's population will be rich or at least much closer to it than it is today. Not only will incomes converge across countries, he said, but also the world will become more peaceful and democratic. He did not deny the existence of enormous problems in every part of the non-OECD world, but he believed that better policies and growing social capabilities would spur growth:

> "A major reason why there are still poor countries is that their economic policies have produced unstable prices and employment, domestic prices out of line with world ones, inefficient nationalized and regulated industries, low trade shares, little foreign capital and technology, and obstacles for the creation of new industries. Such errors are now widely being corrected. Import-substitution policies are being replaced by export-oriented ones, countries hitherto hostile to foreign investment are encouraging it, regulations being reduced, firms privatized, and more (Rowan (2006), p 93)."

Angus Maddison (2007) also has produced a bullish long run economic forecast to 2030, although one with more diverse regional results than the Market First scenario. In his *Contours of the World Economy, 1-2030 AD*, he forecasts the non-OECD group of countries growing almost twice as fast as the OECD countries (3.0 to 1.7 percent) in real per capita terms, 2003-2030. He assumes technological advances will keep growth high in the mature economies and he expects convergence forces will allow China and India to both average about 4.5 percent growth in real terms. Growth will slow over the period as these countries approach the technological frontier and are forced to devote more resources to environmental and welfare issues. He assumes that Latin America will continue on a slow growth path due to outright rejection or half-hearted implementation of pro-growth policy reforms. He projects only 1 percent growth in Sub-Saharan Africa.

The global growth optimism in the Market First scenario is also replicated in the Intergovernmental Panel on Climate Change A1 global warming scenarios which envision very rapid economic growth—3.1 percent real world per capita GDP, 2001-2050—based on increased globalization and rapid introduction to new technology (IPCC, 2009).

The bullishness in all these scenarios comes from similar concepts about economic growth. The projections are based, implicitly or explicitly, on the extended neoclassical growth model described above and assumptions about the same factors that presumably are growth-promoting such as the institutional and policy factors that promote or discourage convergence. Economists at the World Bank and elsewhere are in general agreement on the nature of governance and institutions that work best to promote long-run economic growth:

- Free markets and private property are better at generating growth than centralized government control of production, but a strong government is nonetheless essential to force the rules of peaceful economic behavior and alleviate inevitable market failures.
- Trade and financial market liberalization is needed to spur competition and the flow of investment funds, including increased access to developed-country goods and capital markets.

[23] The Lucas arguments and the exact quotes cited in this paragraph are from Lucas (2000), p 164-166.

- Democratic accountability of government is helpful, to keep both corruption and predation from destroying incentives to work, save, and invest, and to encourage pro-growth spending on education, health, and infrastructure.[24]

But despite wide—not universal—acceptance of these principles there is little agreement on how countries can or should transition to modernity and what outsiders can do to help. It took hundreds of years for Western Europe and North America to develop, from within, the institutions that propel the modern economy and the Washington Consensus ideas provide only general principles, not specific policy guidance. No well-meaning expert has the ability to design a fail-safe program to guarantee economic success even in countries with governments willing to reform. In addition, the application of policies aimed at converting these principles into practice under the guidance of the International Monetary Fund and the World Bank has lead to numerous policy failures, few successes, and much bitterness (Easterly, 2001). There is also some outright political opposition to many of the tenets of this market-oriented approach to economic governance and it is very easy for political leaders to resist or overthrow reform efforts for reasons of intellectual disagreement, ignorance, domestic politics, or personal (or group) advantage.[25]

The Market First scenario also assumes that the OECD countries continue to grow at high rates—high in per capita terms compared to historical norms. This is not implausible. The OECD countries, despite the severe recession of 2008-09, have economic and political institutions designed to generate good economic growth, and large expenditures for research and development are expanding the knowledge frontier in a way that could well lead to significant productivity gains for decades to come. Growth in the countries at the technological frontier depends mainly on human capital development and there is no physical limit on that.[26]

High OECD growth by itself probably hurts the global inequality numbers, but it is helpful to economic growth, and hence poverty reduction, in the non-OECD countries. The OECD countries, however, face their own set of problems, especially dealing with a rapidly aging population that threatens to undermine the social contract that underpins economic success. It is easy to imagine a scenario with much lower economic growth in both the OECD countries and the rest of the world.

## THE TREND GROWTH SCENARIO

In an alternate scenario I calculate what would happen to global poverty if the benign assumptions that drove convergence of the non-OECD countries in the Market First scenario did not occur. Instead, most countries are assumed to continue on the same trajectory they have been on for the last 25 years. For some countries, notably China and India, that is a very good trajectory. But for Latin America, Africa, and the Middle East, recent economic history has not been favorable apart from a few years in the early 2000s when almost all countries participated in an unsustainable global boom (Table 10).

In Latin America, GDP per capita grew an average of only 0.7 percent per year, 1981-2005, while growth averaged 0.5 percent a year in the Middle East/North Africa region. In sub-Saharan Africa, GDP per capita declined an average of 0.2 percent per year, increasing the poverty headcount by nearly 180 million people.[27]

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[24] This list stems from the original "Washington Consensus" list proposed by Williamson (1989). For a more up-to-date discussion see the Commission on Growth and Developoment's *The Growth Report: Strategies for Sustained Growth and Inclusive Development* (2008) and Rodrik's "A Washington Consensus I Can Live With" (2008). See also Mancur Olson's "Big Bills Left on the Sidewalk" (1996) for a discussion of overcoming the collective action problem.
[25] The latter point is extensively treated in Acemoglu and Robinson's *Economic Origins of Democracy and Dictatorship* (2006).
[26] See Peter Schwartz (1999) or Duesterbeg and London (2001) for optimistic discussions about the future of technology.
[27] There was a slight decrease in the Sub-Saharan African poverty headcount ratio which is surprising given the low GDP growth rates. The previous Chen-Ravallion estimate (2004) showed the Sub-Saharan poverty ratio increasing by 5.3 percentage points between 1981 and 2001. My 2008 estimate had the Sub-Saharan poverty ratio increasing 6.5 percentage points between 1980 and 2005.

Table 10

**Poverty Headcounts and Poverty Ratios in the Slow-Growth Regions in 2050**

| | Average annual growth PPP GDP per capita 1981-2005 | Poverty headcount (at $1.25 a day, millions of people | | Poverty headcount ratio % | |
|---|---|---|---|---|---|
| | | 1981 | 2005 | 1981 | 2005 |
| Latin America/Caribbean | 0.7% | 42 | 46.1 | 11.5 | 8.4 |
| Middle East/North Afirca | 0.5% | 13.7 | 11.0 | 7.9 | 3.6 |
| Sub-Saharan Africa | -0.2% | 214 | 391 | 53.7 | 51.2 |
| Non-OECD | 1.9% | 1896 | 1377 | 50.5 | 24.7 |
| World | 1.5% | 1896 | 1377 | 42.0 | 21.3 |
| | | Poverty headcount (at $2.5 a day, millions of people | | | |
| | | 1981 | 2005 | | |
| Latin America/Caribbean | | 107 | 122 | 29.2 | 22.1 |
| Middle East/North Afirca | | 67.6 | 87 | 39.0 | 28.4 |
| Sub-Saharan Africa | | 322 | 614 | 81.0 | 80.5 |
| Non-OECD | | 2732 | 3085 | 72.7 | 55.3 |
| World | | 2732 | 3085 | 60.5 | 47.7 |

*Source:* Chen and Ravallion (2008), except GDP growth from World Bank World Development Indicators

The global food situation is only slightly worse in 2050 than it is in the Market First scenario and it still shows substantial improvement over 2005 (Table 11). In sub-Saharan Africa malnourishment rises only 3 percentage points compared to the Market First scenario but the African people are projected to spend a much higher proportion of their (lower) incomes to cover their food needs.

Table 11

**World Food Supply and Demand in Trend Scenario**

| | World Crop Production million metric tons | Crop Land million hectares | Yield tons per hectare | Crop Loss Ratio percent |
|---|---|---|---|---|
| 2005 | 4190 | 1544 | 2.71 | 30.3% |
| 2050 | 6150 | 1620 | 3.80 | 24.1% |
| *percent change* | 46.8% | 4.9% | 39.9% | |
| *avg. ann. Pct. Change* | 0.9% | 0.1% | 0.7% | |
| | Calories available per person | | | |
| | World | OECD | Non-OECD | Sub-Saharan Africa |
| 2005 | 2,800 | 3,421 | 2,662 | 2,256 |
| 2050 | 3,099 | 3,648 | 3,013 | 2,507 |
| *percent change* | 10.7% | 6.6% | 13.2% | 11.1% |
| *avg. ann. Pct. Change* | 0.2% | 0.1% | 0.3% | 0.2% |
| | Percent of population malnourished | | | |
| | World | OECD | Non-OECD | Sub-Saharan Africa |
| 2005 | 12.4% | 1.9% | 14.8% | 30.7% |
| 2050 | 5.9% | 0.0% | 6.8% | 21.4% |

*Source:* Author's simulation with International Futures Model

In the Trend Growth scenario the per capita growth rate in the non-OECD countries as a whole is about half a percentage point per year less than in the Market First scenario, but the growth assumptions are cut drastically in the countries where most of the poverty is—sub-Saharan Africa, North Africa, and a few Asian and Latin American states. As we saw, the Market First scenario assumes very large increases in economic growth in these countries compared to the past two decades.

What happens to global poverty if economic growth rates do not improve from levels recorded in 1981-2005? In some regions the trend growth assumptions do not do much to raise poverty, even at the $2.50-a-day definition, because there is not much extreme poverty to begin with in the region (i.e., Latin America, although some countries such as Haiti are badly hurt) or because the trend rates of economic growth are high (i.e., India and China). Sub-Saharan Africa, however, which was helped in the Market First scenario by some extremely favorable assumptions about policy changes—if not regime changes—is seriously hurt. By 2050, the extreme poverty rate is three times what it was estimated to be in the Market First scenario (Table 12).

Table 12
**Poverty in the Slow-Growth Regions**

| | 2005 | | 2050–Market First Scenario | | 2050--Trend Growth Scenario | |
|---|---|---|---|---|---|---|
| *millions of people consuming below the $1.25 and $2.50 poverty thresholds* | | | | | | |
| | $1.25 | 2.50 | $1.25 | $2.50 | $1.25 | $2.50 |
| Latin America | 46.1 | 122 | 7.8 | 21.1 | 56.9 | 147 |
| Middle East/North Africa | 11 | 86.7 | 0.7 | 2.5 | 9.4 | 48.1 |
| Sub-Saharan Africa | 391 | 614 | 205 | 533 | 930 | 1364 |
| World | 1377 | 3085 | 245 | 710 | 1120 | 1948 |
| *percent of population* | | | | | | |
| Latin America | 8.4% | 22.1% | 1.0% | 2.7% | 7.4% | 19.2% |
| Middle East/North Africa | 3.6% | 28.4% | 0.1% | 0.6% | 1.7% | 8.9% |
| Sub-Saharan Africa | 51.2% | 80.5% | 11.7% | 30.5% | 53.1% | 77.9% |
| World | 21.3% | 47.7% | 2.6% | 7.6% | 12.0% | 20.9% |

*Source:* 2005 from Chen and Ravallion (2008), 2050 figures from author's calculations.

In the Trend Growth scenario, the trend toward global income equality is stalled. From a global Gini coefficient of 68.4 in 2005, the Market First scenario pushes it down to 64.8 in 2050. In the Trend Growth scenario, the global Gini coefficient barely shifts to 67.9 in 2050.

### Absolute income gaps expand in both scenarios

The absolute income gaps between the OECD and the non-OECD do not shrink in either scenario. In the optimistic Market First scenario, income gaps rise from almost $30,000 per person in 2005 (in PPP dollars, 2005 price levels), to $98,000 in 2050, even though the per capita GDP growth rate in the non-OECD is almost a percentage point higher than the OECD average annual growth rate over the 45 years of the scenario. The ratio of OECD to non-OECD per capita income falls sharply, from 7.4 to 5.3, but the absolute gap more than triples.

However lamentable, a widening of the gap in absolute terms is almost inevitable unless the OECD countries stop growing. If the OECD failed to grow at all for the next 45 years (versus 2 percent or more in these scenarios), it would take the non-OECD 57 years at 3.6 percent a year growth (as in the Market First scenario) to catch up with the average OECD GDP per capita income figure of $34,359. Even if one thought this were a desirable result, it is likely that lower growth in the OECD would lead to lower growth in the rest of the world—it is hard to imagine the non-OECD countries growing robustly if the OECD countries are stagnant.

Simulations with the IFs model suggest that long-run Sub-Saharan African growth would fall between 40 and 140 percent as much as OECD growth falls, depending on assumptions about protectionism and technology. African economic growth in the IFs model is also quite sensitive to the level of foreign aid. Raising foreign aid contributions, gradually, to 0.75 percent of OECD GDP has no discernible impact on OECD growth, but it increases sub-Saharan African growth by almost 1 percentage point a year and reduces the sub-Saharan poverty headcount by 120 million by 2050. The model simulations implicitly assume that most of the aid (an extra USD6.5 trillion over 45 years) is productively invested in physical and human capital.[28]

In all of these scenarios, extreme poverty becomes much more highly concentrated in sub-Saharan Africa because higher economic growth in Asia—particularly in India and China—removes hundreds of millions of people from the global poverty headcounts. Assuming 2 percent per year population growth, sub-Saharan Africa needs 2 percent per year per capita GDP growth (and constant within-country distributions) just to keep the extreme poverty headcount from rising. Faster growth—2.5 percent per year in the Market First scenario—cuts the headcount from 391 million in 2005 to 205 million in 2050, and higher growth rates are possible. In addition to raising GDP growth, however, lowering population growth or flattening within-country distributions could also help reduce the poverty headcount. If somehow, sub-Saharan Africa could cut its population growth in half but still manage GDP per capita growth of 2.5 percent a year, the 2050 poverty headcount would fall below 100 million people. If we combine the 2.5 percent GDP per capita growth rate with the low population growth rate, and with the Higgins-Williamson favorable distribution forecast, extreme poverty in sub-Saharan Africa would almost disappear.

## Comparison to other long-range growth and poverty projections

One of the most famous pessimistic scenarios in the literature was created and periodically revised by Meadows and her associates in the *Limits to Growth* books (1972, 1992, and 2004). They claim that present trends in population, industrialization, pollution, and resource depletion will make current world economic growth rates unsustainable. They use a very different sort of model than the neoclassical growth model described above. The World3 model[29] is based on the idea that world systems, especially the agricultural system, has a finite carrying capacity that has been nearly reached. In their reference scenario global output per capita peaks around 2025 and goes into irreversible decline, mainly because of the collapse of world agriculture. Their model contains no country detail or poverty estimates, but it clearly portrays a much poorer planet than that envisioned even in the Trend Growth scenario. The major difference between the Limits to Growth scenarios and the more optimistic ones discussed in this paper is pessimism about the possibility of technological change to overcome perceived physical constraints.

Another line of thinking is represented by Immanuel Wallerstein (2004) and "World Systems Analysis". In this approach, instead of the world moving toward an improved and globalized capitalism as envisioned in the Market First scenario, the capitalist world-economy collapses due mainly to underconsumption and resentment of the peripheral countries toward the core. Unfortunately for our purposes Wallerstein presents no scenario of future developments after the collapse.

Ian Bremer (2009) does not predict the collapse of global capitalism but he does worry about a retreat from the market principles reflected in the Washington Consensus and a growing embrace of "state capitalism". He discusses the rise of state-owned energy companies, the renationalization of strategic industries in many non-OECD countries, and the growth of sovereign wealth funds.

> "The free-market tide has now receded. In its place has come state capitalism, a system in which the state functions as the leading economic actor and uses markets primarily for political gain (Bremer (2009), p 41)."

Bremer sees this development as anti-poor. By distorting incentives, creating vast new opportunities for corruption and rent-seeking state capitalism will inevitably slow growth and limit poverty reduction. State capitalism promotes protectionism and subsidies that will further restrict growth. Eichengreen and Irwin (2007) argue that, at best, there will be a long pause in trade policies of the United States of America geared toward liberalization and that "past gains from liberalization will get whittled away as countries backslide on previous commitments" (2007, p 25). A recent paper by Hillebrand (2009) using empirical estimates by Estavadeordal and Taylor (2008) estimates that a global retreat into protectionism (with tariff levels going back to pre-Uruguay round levels) might improve income inequality in a few countries, but it would cut

[28] There is, of course, no guarantee that aid will be well spent. See Sachs, (2005), Easterly (2002), Collier (2007), and Moyo (2008) for differing views on the utility of foreign aid.
[29] The computer model is available from the publishers at www.chelseagreen.com

economic growth by almost a percentage point a year to 2035, and raise the global poverty headcount by at least 170 million people.

## CONCLUSIONS

This paper has taken a long view of economic growth, poverty, and inequality—a view from 1820 to 2050. While acknowledging that the data are far from perfect and the methodology to fill in the gaps requires a substantial amount of guesswork, key contributions in the literature, especially Maddison (1995, 2001, 2003) and Bourguignon and Morrisson (2002), have established that world economic growth has been, on average, very high since 1820, high enough to cause global poverty to fall dramatically. More recent work, especially by Chen and Ravallion (2004, 2008), has shown that the downward trend in the global poverty rate accelerated after 1980 and even the poverty headcount has started to show a significant decline.

This paper has projected world poverty rates, headcounts, inequality measures, and absolute income gaps to 2050, based on two different scenarios for global economic growth. In the optimistic growth scenario the global poverty rate at the $1.25 a day standard falls sharply, from 21.3 percent in 2005 to 2.5 percent in 2050 and the number of people living in extreme poverty falls by 1.1 billion people. The absolute gap between per capita incomes in the OECD and the non-OECD countries, however, and the global Gini coefficient remain high.

In an alternate scenario, I assume that the regions that have been lagging (sub-Saharan Africa, the Near East, and Latin America) do not transition onto a high growth path. This results in much higher poverty levels: almost 900 million more people living in absolute poverty in 2050 than in the optimistic scenario. I have considered, but not explored empirically, even more depressing scenarios. Resource constraints, if not met by technological solutions, will surely make the poverty estimates shown here worse. A breakdown of the world capitalist system as envisioned by Wallerstein, or even a gradual turning away from the system that has done so much to reduce global poverty over the last two centuries would be disastrous.

## TECHNICAL APPENDIX

This appendix discusses in greater detail several of the methodological issues raised in the text.

### Purchasing Power Parity

We could compare GDP and incomes across countries at market exchange rates and for countries at similar standard of living and price levels and it would not be incorrect to do so. To compare GDP and living standards across countries at widely different levels of development, economists usually prefer to use purchasing power parity (PPP) ratios (between all currencies) which try to estimate how much of any given currency will be required to buy an equivalent amount of the same quantity and quality of goods in any country. The International Comparison Project (ICP) undertakes a massive international survey every few years to create new estimates of these PPP ratios at a given point in time. See the World Bank's *Global Purchasing Power Parities and Real Expenditures* (2008) for details.

To study incomes and living standards and poverty over time, the producers of the commonly used global economic databases (the World Bank (World Development Indicators database), Angus Maddison (2003), and the Penn World Tables (PWT)) start with PPP GDP estimates for every country at a point in time, and then estimate past and future PPP GDP based on national income account data. This methodology has severe theoretical drawbacks, especially the implicit assumption that the PPP ratio between currencies is constant. Efforts to replace this methodology have been considered by Dowrick and Akmal (2005) and Feenstra and Rao (2008) among others, but their ideas have not yet been adopted by the global database producers.

### The Lorenz curve and Gini coefficients

The Lorenz curve is a widely used technique for showing inequality in income (or any other quantity distributed across a population). It shows the cumulative share of income held by cumulative shares of the population. If income is distributed evenly, then each 10 percent of the population gets 10 percent of the total income, and the curve is a straight line with a 45 percent slope. The more unequal the distribution, the greater is the bow in the curve to the right of the 45 percent line. The Gini coefficient is a summary statistic that measures the area between the 45 percent line and the Lorenz curve. Gini coefficients range in principle between 0 (perfect equality of income) and 100 (perfect inequality—one person in a population gets all the money). In practice, GDP per capita or consumption per capita Gini coefficients range from the mid 20s (some Scandinavian countries) into the 60s and 70s (some African countries).

### Estimating and Forecasting Poverty Levels

Both the Chen-Ravallion methodology and the Bhalla SAP technique estimate Lorenz income distribution curves based on household survey data. Chen and Ravallion estimate poverty headcount ratio for a given poverty level directly from the Lorenz curve. The SAP procedure uses a regression technique to estimate the incomes of each percentile of the population of each country. If we know total consumption in a country (either from the household survey data as in the Chen-Ravallion work or from the national income accounts as in Bhalla), then we can estimate the consumption per person in each percentile of the population.

The SAP methodology leaves us with three discrete components of change in poverty headcounts: economic (GDP) growth, shifts in the share of GDP going to private consumption, and shifts in the distribution of consumption within a population.

The methodology used by Chen and Ravallion (2004) and by the World Bank (2006 and 2007) to estimate historical poverty levels is less convenient for forecasting because it uses a cross-country regression to posit a constant elasticity of poverty reduction to per capita income growth. The constant elasticity assumption is not very reliable for extending projections very far in the future given that we are interested in movements below or above a fixed poverty threshold. A country's incomes just below the threshold can cross the threshold with only a low level of growth while a country with incomes far below the threshold can have high rates of growth without moving many people out of extreme poverty (see Hillebrand (2008) for a fuller discussion).

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# WORLD FOOD AND AGRICULTURE TO 2030/50

## HIGHLIGHTS AND VIEWS FROM MID-2009[1]

**Nikos Alexandratos**[2]

## CONTENTS



[1] Paper for the Expert Meeting on "How to Feed the World in 2050," FAO, Rome, 24-26 June 2009 (revised 25 July 2009). The views expressed in this information product are those of the author(s) and do not necessarily reflect the views of the Food and Agriculture Organization of the United Nations. Thanks to the colleagues in FAO's Markets and Trade Division preparing the projections of the 2009 *OECD/FAO Agricultural Outlook* for making available preliminary results of ongoing work.

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## ABSTRACT

We examine the long-term projections in the FAO Study World Agriculture: Towards 2030/50, prepared in the years 2003-05 (from historical data to 2001 and base year 1999/2001[3]) for selected broad country- and commodity-group aggregates. An overview of the Study's findings is attached as Annex. The objective of the examination is to establish if and to what extent the projections are still valid as predictions of what may be in store in world food and agriculture to mid-century. We test the projections against (a) actual outcomes, as far as available data permit, in the first eight years of the projection period (to 2008), and (b) against the just-completed 10-year projections 2009-2018 of OECD/FAO, both with and without the quantities of crops used as biofuels feedstocks. On both counts, but without accounting for the impact of biofuels (not included in the Study), the projections have been found to be still broadly valid at the level of the aggregates considered.

A fresh look is required to take on board the possible effects of biofuels. The existing medium-term projections of biofuels production and, in some cases, also of the crop quantities to be used as feedstocks, indicate that further growth is in prospect, though not at the very high rates of the last few years. The quantities of cereals by which, in these projections, world aggregate consumption would be higher because of biofuels would be still relatively modest (7 percent of world consumption in 2018, up from the current 4.8 percent), much of which will likely come from increased production over and above what it would be without biofuels. However, the potential exists for biofuels to be a major disruptive force conditioning agricultural futures, because of the growing integration of the energy and agriculture markets. This is a theme which, together with the possible impact of climate change, must inform all future attempts to speculate about long-term futures of world food and agriculture.

We also examine the Study's projections of food consumption (in terms of kcal/person/day) and the numbers undernourished in the developing countries in the light of some drastic revisions in the historical food consumption data and the parameters used to compute such numbers, as well as in the projected populations. Such revisions indicated that per capita food consumption in the Study's base year 99/01 was lower than known at the time. We had to adjust the projected food consumption levels of the Study to account for such revisions so that they can be compared with the latest published estimates (in SOFI08) of per capita consumption and numbers undernourished. Following such adjustments, the projected per capita food consumption (Kcal/person/day from all food commodities) in many developing countries is lower than in the Study. As a consequence, and given the revised higher population projections, the pace of decline in the numbers undernourished, slow and inadequate as it was in the projections of the Study, may turn out to be even slower. Achievement of the 1996 World Food Summit (WFS) target of halving the numbers undernourished in the developing countries by 2015 (from that in 1990/92) may recede well further into the future.

## 1. INTRODUCTION

This paper sketches out the possible evolution of world food and agriculture to 2050 in terms of the key variables (production and consumption of the main commodity groups and the implications for food and nutrition in the developing countries). It presents a view of how these variables may evolve over time, not how they should evolve from a normative perspective in order to solve problems of nutrition and poverty. The basis for the contents of this paper are Study's food and agriculture projections to 2015, 2030 and 2050, prepared in the years 2003-05 and published in 2006 (FAO, 2006 – hereafter referred to as *Interim Report* - IR). For easy reference, the Section on the main findings from Chapter 1 of the IR (Overview) is attached here as Annex. The reader is referred to the full IR for details.

The projections of the IR were based on historical data from the complete FAO (Faostat) Food Balance Sheets (FBS) available for all countries. The FBS data available then went up to 2001. Hence the base year of the

[3] Notation: 1999/2001 stands for the 3-year average 1999-2001; 2006/08-2018 stands for the period between 2006/08 and 2008. Ton = metric ton

projections was the 3-year average 1999/2001. The evaluation of the projections in terms of the rainfed and irrigated land use and yield configurations underlying the production projections against the land and water potentials of each country was not performed on that occasion. The latest attempt in this area dates from work carried out in 2000-2002 with projections going to 2030 from base year 1997/99 and published in 2003 (Bruinsma, 2003), using the land potential estimates from an older edition of the Global Agroecological Zones Study of FAO and IIASA (GAEZ, Fischer *et al*, 2002). For the IR the evaluation was delayed while waiting for fresh estimates of such potentials to be produced by the revision of the GAEZ. These estimates from the new GAEZ are currently being prepared for publication (Fischer *et al*, forthcoming) but not yet available in the format required for use in analyses of the IR-type. In the meantime for this EM event an attempt is made to unfold the land use and yield growth implications of the production projections to 2030/50 of the IR using the old GAEZ estimates of land potentials. These are presented in a separate paper (Bruinsma, 2009).

Naturally, presenting in mid-2009 projections completed in 2005 and based on historical data up to 2001 and on the outlook for key exogenous variables (the population and GDP projections) as known then presents some problems. The last few years have witnessed upheavals that must be taken into account in passing judgment as to how relevant our views of the future of four years ago are today. In the first place, there has been the intrusion of the energy markets into those for agricultural produce via the links of the high energy prices and the boost this gave to the demand for crops as biofuel feedstocks, helped by government policies favouring such use of crops. It is now widely accepted that this was a key factor explaining the food price surges up to mid-2008. Secondly, the overall economic outlook is being severely affected by the ongoing economic crisis, though the issue of how important this may prove to be for the longer term is moot. Additionally, the latest demographic assessments (U.N. Assessment of 2006 – U.N., 2007), and the just released Assessment of 2008 suggest that projected populations to 2050 may be higher than those of the 2002 Assessment (U.N., 2003) used in the IR, particularly in several countries of sub-Saharan Africa[4].

It would be desirable to account for these new circumstances by re-doing the entire projections exercise. This proved, however, practically impossible given the great country and commodity detail involved (see IR, pp. 66-68) and the delay in updating FAO's FBS data (see Box 1). The second best option is to review the IR projections on the basis of the FAO data set used predominantly for the current monitoring published (for major countries and aggregates only) in the six-monthly *Food Outlook* and largely also for the annual OECD/FAO medium-term projections (hereafter referred to as CBS data[5]). The current round of these medium-term projections for the 10 years 2009-18 has just been completed (OECD/FAO, 2009[6]). These projections *ex hypothesi* incorporate all the information available at present, concerning both developments in the last few years as well as the views of what may be in store up to the year 2018 in terms of the overall economy, the energy sector and prices. As such, the projections provide a valid benchmark to compare with those of the IR in order to draw inferences about the continued validity, or otherwise, of the IR projections. Comparability is limited by differences in commodity coverage/specifications and in country groups distinguished (see *Box 1*). However, some comparisons at the level of large country aggregates (developing, developed, world) can be made to provide a reality check of the IR projections. Regional level projections are presented only in Section 4.

In what follows we run such a reality check, together with a presentation of the IR projections, for a few commodity aggregates, focusing particularly on cereals (sum of wheat, rice, coarse grains) and meat (sum of bovine, pigmeat, poultry, ovine, in carcass weight), for two reasons:

a) they do not present major comparability problems with the commodity specifications of the IR, and

[4] In the 2002 Assessment, world population was projected to reach 8.9 billion by 2050. The projection is 9.2 billion in latest 2008 Assessment. The projections for the IR developing countries of sub-Saharan Africa are 1.5 billion and 1.7 billion, respectively.
[5] The CBS data used here in text, tables and graphs are updated as of 3 July 2009.
[6] Data and projections in xls available in
http://www.agri-outlook.org/document/6/0,3343,en_36774715_36775671_40969158_1_1_1_1,00.html

b) they have held centre-stage in the debate on the food price surges: at the early stages of the price surges a quasi-consensus view was being propounded that spurts in the food/feed demand, particularly in the fast growing emerging economies (India, China) with their allegedly voracious appetite for meat, were a key determinant. This is no more a proposition many would defend, though it is an idea hard to die[7] (see Alexandratos, 2008).

In addition, we present comparisons for the commodity "vegetable oils". Here comparisons are of a more limited nature because of incompatibilities in the commodity specifications.

***Box 1. The Data Situation***

*Before proceeding, a note on the data situation is in order. In preparing the projections published in the Interim Report and on previous work we had used exclusively FAO's Faostat data sets of production and trade of all commodities, including non-food ones like cotton and rubber, as they had been standardized and processed into the Supply-Utilization Accounts (SUAs) and the FBSs. Revisiting these projections in mid-2009 taking into account recent developments requires that we inspect them against SUA/FBS data updated to a more recent year when many changes occurred due to the advent of biofuels and the surge in food prices. Yet, such data are not yet available: at the time of writing (May, 2009) FAO's published SUA/FBS data go only to 2003 and provisional unpublished ones to 2005. The latter estimates include some really radical revisions in the historical data, including those for 1999/2001, the base year of the IR, particularly as regards the per capita food consumption which is of key importance in diagnosing the nutritional situation (see Section 4 below). Faostat non-SUA/FBS data go to 2007 for production and to 2006 for trade. It is obvious that the existing updates of the SUA/FBS data do not provide an adequate basis for revisiting the projections of the Interim Report in the light of new circumstances.*

*In what follows we resort to the above-mentioned CBS data set. It covers a more limited number of commodities compared with the coverage of the SUA/FBS data, e.g. it does not cover key food commodities like roots and tubers or pulses which are the mainstay of diets in several countries. It has data up to 2008 (the data of this latter year are often estimates) for production, trade and stocks (hence also the implicit total domestic disappearance or consumption for all uses). It often includes, though not in all cases, categories of utilization (food, feed, etc). The country coverage and detail in this data set is not always sufficient to generate the country groups used in the projections of the Interim Report (shown in FAO, 2006, p. 67). For example, Romania and Bulgaria were projected as part of the group "Other Eastern Europe". Likewise, the ten countries that entered the EU in 2004 were projected as a group separately from that of the older 15 EU countries. The CBS do not generally show data for recent years separately for these countries individually but only for the EU as a whole. This makes it impossible to generate data suitable for comparing the IR projections for many country groups with actual outcomes to 2007 and the estimates for 2008. For this reason, in the following discussion data are compared for the developing countries and the rest of the world or the developed countries. The latter comprises the groups "Industrial" and "Transition" of the Interim Report.*

*Problems of non-comparability of the data because of differences in the commodity specifications are even more serious. For example, in the IR the commodity "sugar" includes all sugar crops and derived products (including non-centrifugal sugar which is important in countries like India) converted into raw sugar equivalent quantities. The CBS does not use the same coverage, therefore direct comparison is not possible. The same goes for the commodity "vegetable oil": in the IR specification it comprises all oilcrops, oils and derived products converted into oil equivalent. This means that consumption of oilseeds directly as pulses (e.g. soybeans, groundnuts) or in other forms, is counted as consumption of the oil content equivalent in the IR data and projections but not in those of the other data bases and projection studies.*

[7] See, for example, a recent article in the *Economist* ("Green Shoots", March 21st, 2009) holding that the steady increase in demand from poorer countries is the single largest cause of rising prices! The correct statement is that increases in the demand of the developing countries represent the major component of global demand growth, but this is nothing new. It has been with us for some time and was present even when prices were not rising and often falling. It is the biofuels that caused the spurt in global demand in the years of price spikes.

## 2. INTERIM REPORT PROJECTIONS AND REALITY CHECKS

A major point made in the Interim Report was that the growth of demand of the developing countries and the world for both cereals (excluding their use for biofuels which was not accounted for in the IR) and meat would be gradually decelerating. Yet, as noted, in the debate on the food price surges of the recent period up to mid-2008, it was often stated (or rather assumed, given that food consumption data were hardly available) that the spurt in the demand for meat and the associated demand for feed cereals in the developing countries, particularly China and India, was a major factor explaining why cereal prices surged. So the first question to ask is whether the predicted deceleration is actually happening. Then we should examine whether the OECD/FAO projections sketch out future trajectories that are close enough, or otherwise, to those of the IR.

### 2.1 Cereals

Table 1 compares the Interim Report's (IR) projections with the most recent data for 99/01 and the latest three-year average 2006/08, with and without the cereals use for biofuels. Figure 1 illustrates the relevant trajectories.

*Consumption, Developing Countries*
We had projected a gradual slowdown in the growth of the cereals consumption (all uses, not only food) in the developing countries, to 1.8 percent p.a. in the first sub-period 99/01-2015. *Is it happening*? It is. Over the period 99/01-06/08 growth decelerated to 1.8 percent p.a. from 3.0 percent in the 1980s and 2.0 percent in the 1990s, while per capita consumption increased to 244 kg in 2006/08. Therefore, on this criterion, the IR projections seem to be on the right track. *Will they continue to be so in the future*? The OECD/FAO medium-term projections to 2018 foresee aggregate consumption of the developing countries to rise to 1 462 million tons (mt) in 2015 (close enough to the 1 472 mt of the IR – Table 1) and on to 1522 mt by 2018. The IR projections seem to be on the right track also on this criterion.

*Consumption, Developed Countries*
The IR had projected a rebound of growth in the early years of the projection period because of the expected recovery of the transition countries after the deep declines of the 1990s. It did rebound, to 1.4 percent in 99/01-06/08, i.e. by more than projected in IR (0.6 percent in 99/01-2015). However, much of the rebound was due to the growing use of grains for biofuels (overwhelmingly maize for ethanol in the United States of America[8]) and the associated price rises. Without it, the rebound was much more modest (0.4 percent p.a.), lower than in the IR projections. That it was lower can be interpreted as reflecting the fact that not the entire use of maize for ethanol represented additional consumption: part of it was met by reductions in, mainly, the use of grain for livestock feed following the higher prices, hence the lower than projected growth of consumption for food and feed (see Section below on biofuels)[9].

What about the future? The OECD/FAO projections foresee faster growth in the developed countries, 1.5 percent p.a. from 06/08-2018, than the IR. However, the OECD/FAO projections of the developed countries *include biofuels* (80 mt in 06/08, 172 mt in 2018). Excluding such use from the projections, the growth rate of consumption for all other uses from 06/08-2018 is reduced to 0.8 percent. In the end, the IR projection for 2015 of 815 mt compares with the 945 mt (with biofuels) and the 777 mt (without biofuels) of the OECD/FAO projections for the same year. Again, it is implicit that the growth of biofuels will squeeze out some of the IR projected consumption for food and, predominantly, feed. Overall, therefore, the IR projections for the developed countries (excluding biofuels use) seem to be on track.

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[8] Use of maize for fuel alcohol in the United States of America had reached 91 mt in 2008 (www.ers.usda.gov/data/feedgrains/FeedGrainsQueriable.aspx). This is the only source with data of cereals use for biofuels extending back to 1980. Data for more recent years are available for some other countries, in the data set used in the OECD/FAO projections: they indicate, for 2008, 6 mt in the European Union (EU27), 2 mt in Canada and some 4 mt in China.
[9] It is noted that not all the maize used for biofuels should be considered as subtracting an equal amount from supplies available for feed: some 30 percent of the maize used for biofuels is returned to the feed sector in the form of by-products (mainly distillers' dry grains - DDGs).

*Consumption, World Totals*

The sum of the above two country groups shows that for the world as a whole consumption growth was higher (1.6 percent p.a. from 99/01-06/08) than the projected 1.4 percent from 99/01-2015. It was, however, lower (1.3 percent p.a.) than projected in the IR if the United States of America's maize use for biofuels is excluded from world consumption. The OECD/FAO projections for 2015 are 2407 mt (with biofuels) and 2235 mt (without biofuels) vs. the 2287 mt in the IR projection for the same year.

*Conclusion on Cereals Consumption*

By and large, the trajectory of actual consumption to 2008 of the world as a whole and also separately for the developing and developed countries (excluding the biofuels component) follow fairly closely the IR projection paths (see Figure 1), which is one of gradually decelerating growth. Ergo, we could use the existing IR projections (at least for these large country aggregates and the world as a whole) and then add on top one or more alternative views of future use of cereals for biofuels (we address this topic later on in this paper, while a companion paper for this EM delves more in depth into this topic – Fischer, 2009). In this way we could get a path of possible developments in the global demand for cereals over the time horizon of the projections that would be compatible with the IR projections, the developments to date, the medium-term outlook of OECD/FAO and at least one view of cereals use for biofuels. Obviously, updating the Study's views of cereals futures for individual countries and small country groups requires a fair amount of work to run similar reality checks at country level, while taking on board also the drastic revisions of the FBS historical data on food consumption for all commodities (discussed in Section 4, below)

*Production and Net Imports, Developing Countries*

The interface of the production historical data and the projections is not as neat as those for consumption, given fluctuations, caused by both weather and policies. The data of the developing countries production are plotted in Figure 2 (also shown in Table 1). Production was nearly stagnant over the period 1996-2002 (1023 mt in 96/98, 1030 mt in 2001/03), while consumption kept growing and stocks were being depleted. This was one of the factors that presaged the price spikes that followed in the subsequent years (Alexandratos, 2008). During this period, almost all the increases in consumption were met by stocks drawdown. The role of China has been particularly important in these developments during this period: the country started running down the huge stocks it had accumulated in the 1990s (closing stocks of 309 mt in 1999, 84 percent of annual consumption, falling to 148 mt by 2005, 40 percent of consumption[10]). From 2003 onwards there was a rebound in production (reaching 1205 mt in 2006/08). During this latter period, the production increases were more than sufficient to meet the growth of consumption. Indeed part of the production increases went to rebuild stocks (Figure 3). China's role was important also in this second period. Without China, the turnaround from stock depletion to stock rebuilding is much less pronounced, though still evident in the data.

It is important to note that in both periods, changes in net imports played a minor role as contributors to changes in aggregate consumption. They fluctuated in the range 91 mt (2003) - 136 mt (2008). The IR had projected net imports to play a larger role as contributors to the growth of consumption in the developing countries. They were projected to rise from the 112 mt in 99/01 to 168 mt in 2015 and on to 232 mt and 297 mt in 2030 and 2050, respectively. The OECD/FAO projections have 140 mt in 2015 and 154 mt in 2018. If developments in the first half of the current decade are a harbinger of things to come, we may need some radical re-thinking of how we view the future of the developing countries in terms of growing dependence on imported cereals. Lower imports than projected in the IR mean lower projected consumption and/or higher projected production. We have seen that consumption growth of the developing countries is largely on the projected path. Therefore, if projected imports must be lower, it is the production projections that must be revised upwards. This is asking the question: is the IR projection of 1.6 percent p.a. from 99/01-2015 too low in the light of the production growth rebound of recent years (2.3 percent from 99/01-2006/08)?

[10] Problems associated with China's huge stocks accumulated by the late 1990s included overflowing granaries and losses due to quality deterioration as well as large financial losses from sales (domestic and export) at below-cost prices. These problems prompted policy reforms to reduce stocks. They included some relaxation of the policies that obliged farmers to produce cereals (OECD, 2005:37; see also USDA, 2001).

Before jumping to conclusions, we need to take a closer look at the production increases and pose the question whether the acceleration of growth is likely to prove durable or it is the result of extraordinary circumstances. This requires a look at the data for individual countries. Appendix Table A1 lists the 29 developing countries (accounting for 16 percent of cereals production of the developing countries in 99/01) which in the period 99/01-06/08 achieved cereals production growth rates exceeding 4 percent p.a., 5.7 percent p.a. as a group, up from 1.7 percent p.a. in the 1990s. For several of them the spurt in growth of the last few years represented recoveries from troughs in the preceding years. Such growth rates are certainly not very informative for judging long-term growth prospects.

If we were re-doing the IR projections today, we would certainly want to revisit the production projections of the individual countries in the light of developments in the last few years. The key issue is, of course, whether this would affect in any significant way the aggregates for all developing countries and the prospects for the growth of their net cereals imports. For this we can resort to the OECD/FAO projections to 2018. In these projections, the spurt in the growth of production of the period 99/01-2006/08 (2.3 percent p.a.) is not maintained[11]: they project a growth rate of 1.3 percent p.a. from 2006/08 to 2018. Their projected production for 2015 is 1327 mt vs. 1304 in the IR (Table 1). We also saw that their consumption is somewhat lower than that of the IR. By implication, their projected net imports, being the difference between two much larger numbers, are lower than those of the IR for 2015, 140 mt vs. 168 (Figure 3).

Much of the difference in net imports is due to India and China[12]: in the IR they turn into modest (for their size) net importers by 2015, while the OECD/FAO projections have them as continuing small net exporters (6.4 mt in 2015 and 5.1 mt in 2018). Excluding India and China, the two projections of net imports for 2015 are close – 143 mt in the IR, 146 mt in OECD/FAO. China and India have the potential of influencing decisively the cereals trade prospects of the developing countries. The two countries together had been net importers in the past but became net exporters after 1999, reaching peak net exports of 26 mt in 2002 after which net exports declined to 4-6 mt annually in the last 4 years 2005-08.

A few years ago these two giants were seen as turning into net importers again over the medium term. Thus, the 2004 issue of the Food and Agricultural Policy Research Institute (FAPRI) projections to 2013 had them as net importers of 11 mt in 2013. The latest (FAPRI, 2009) edition has them as net exporters of only 1 mt. in 2018. In like manner the OECD Agricultural Outlook of 2004 had China becoming a significant net importer[13]. A recent International Food Policy Research Institute (IFPRI) report (Rosegrant *et al*, 2008, Figure 4.7) has, in its baseline scenario, China's net cereals imports exceeding 50 mt in both 2025 and 2050 and India remaining net exporter in 2025 and turning into net importer in 2050. In conclusion, the net trade position of the developing countries, being the difference between the much larger numbers of production and consumption, remains sensitive to even small variations of these two larger numbers. Views about the future cereals trade positions of China and India can cause any outlook of the developing countries import needs to swing around. As noted, such views tend to change over time. Back in the mid-90s, Lester Brown (1995) considered the prospect of burgeoning cereals imports of China as a major threat to world food security, a clear exaggeration at the time (see critique in Alexandratos, 1996) and even more so at present. Many people seem to be mesmerized by the hugeness and high

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[11] The latest cereals production forecast for 2009 for the developing countries indicates virtually no increase over that of 2008 (FAO, *Food Outlook*, June 2009)

[12] China's net trade position does not include those of the Taiwan Province and the Hong Kong SAR, both net importers to the tune of 7 mt annually in the last ten years and projected to remain so in the future. Thus, all China is really a net importer of cereals, both at present and in the projections.

[13] "From a net exporter of both wheat and coarse grains at the beginning of the *Outlook*, China could become a significant importer of cereals assuming that the TRQs, implemented by China under the WTO accession agreement, will be used efficiently. By the end of this decade, China could import more than ten times as much wheat, coarse grains and rice as in the recent past. Both wheat and rice import quotas are projected to become filled at least in some years, and coarse grain imports, already by far the largest part of Chinese cereal imports, could reach levels equivalent to twice the import quota for maize". *OECD Agricultural Outlook 2004-2013*, (p.52)

economic growth rates of China and its apparently voracious appetite for livestock products and food in general. This may be true (for some time) for things such as energy and metals, much less so for food: the income elasticity of the demand for food tends to decline rather rapidly, limited as it were by the elasticity of the human stomach. The IR projection of the status of China and India as modest net importers by 2015 reflected the dominant view of a few years ago. There is no compelling reason for changing the long-term projections just now, but the matter should certainly be kept under constant review.

*Production, Developed Countries*
IR had projected an acceleration of developed country production (not accounting for the effects of the biofuels) in the first projection sub-period (0.9 percent p.a. from 99/01-2015, up from zero in the 1990s) because of the expected recovery in the Transition countries. The advent of the additional demand for biofuels led to production increases even faster than projected in the IR, 1.3 percent p.a. from 99/01-06/08 (Table 1), a growth rate significantly influenced by a quantum jump of 13 percent in 2008, following the price spikes. The OECD/FAO projections foresee even higher growth in the future (1.7 percent p.a. from 2006/08-2018), largely because of growing use for biofuels. The latter are projected to just over double, almost all of it in the developed countries. If we assumed that all cereals used for biofuels were from home production in the developed countries, then, without them, production in 2015 would be 920 mt vs. 985 mt in the IR. This difference can be attributed in part to the above-mentioned possibility that biofuels use of cereals would squeeze out some of the demand for other uses (mostly feed) and in part to the lower net imports required by the developing countries in the OECD/FAO projections, as discussed above.

*Production, World*
For the World as a whole (the sum of the developed and developing countries) the IR projection is 2287 mt for 2015. This compares with the 2416 mt (with biofuels) or 2244 mt (without biofuels) of the OECD/FAO projections for the same year. If it were not for the biofuels, the IR projection of 3012 mt for 2050 would not be in need of major revision. However, the advent of the biofuels requires that we must at least speculate on possible upwards revisions, perhaps to some 3150 mt, as discussed in Section 3 on biofuels.

**Table 1** **Cereals (Wheat, Rice milled, Coarse Grains): IR Data to 2001 & Projections vs. Revised CBS Data to 2008 & Oecd/Fao Proj. to 2018**

| | Million Tons | | | | | | Growth rates - % p.a. | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **1999/2001** | **2006/08** | **2015** | **2018** | **2030** | **2050** | 80-90 | 90-00 | 99/01-06/08 | 06/8-2018 | **99/01-2015** | **2015-30** | **2030-50** |
| **CONSUMPTION** | | | | | | | | | | | | | |
| World -IR data & Projections (excl. biofuels) | 1,866 | | 2,287 | | 2,677 | 3,010 | | | | | 1.4 | 1.1 | 0.6 |
| *World - CBS data* | *1,900* | *2,130* | | | | | *1.9* | *1.0* | *1.6* | | | | |
| *USA - Maize for Ethanol (USDA data)** | *16* | *74* | | | | | *20.2* | *4.5* | *24.4* | | | | |
| *World - CBS data excl. USA maize Ethanol* | *1,884* | *2,056* | | | | | *1.9* | *0.9* | *1.3* | | | | |
| *World - oecd/fao proj. (incl. biofuels)* | | *2,121* | *2,407* | *2,490* | | | | | | *1.5* | | | |
| *World - oecd/fao proj. biofuels* | | *84* | *172* | *175* | | | | | | *6.9* | | | |
| *World - oecd/fao proj. (excl. biofuels)* | | *2,037* | *2,235* | *2,314* | | | | | | *1.2* | | | |
| Developing Countries - IR data & Projections (excl. biofuels) | 1,125 | | 1,472 | | 1,799 | 2,096 | | | | | 1.8 | 1.3 | 0.8 |
| *Developing - CBS data* | *1,148* | *1,301* | | | | | *3.0* | *2.0* | *1.8* | | | | |
| *Developing - oecd/fao Proj.* | | *1,301* | *1,462* | *1,522* | | | | | | *1.4* | | | |
| Developed Countries - IR data & Projections (excl. biofuels) | 741 | | 815 | | 877 | 914 | | | | | 0.6 | 0.5 | 0.2 |
| *Developed - CBS data* | *752* | *829* | | | | | *0.8* | *-0.4* | *1.4* | | | | |
| *Developed - CBS data excl. US maize Etha* | *736* | *755* | | | | | *0.7* | *-0.5* | *0.4* | | | | |
| *Developed - oecd/fao proj. (incl. biofuels)* | | *820* | *945* | *967* | | | | | | *1.5* | | | |
| *Developed - oecd/fao proj. biofuels* | | *80* | *168* | *172* | | | | | | *7.1* | | | |
| *Developed - oecd/fao proj. (excl. biofuels)* | | *740* | *777* | *796* | | | | | | *0.7* | | | |
| **PRODUCTION** | | | | | | | | | | | | | |
| World -AT data & Projections | 1,885 | | 2,290 | | 2,679 | 3,012 | | | | | 1.3 | 1.1 | 0.6 |
| *World - CBS data* | *1,887* | *2,147* | | | | | *1.6* | *0.9* | *1.9* | | | | |
| *World- oecd/fao proj.* | | *2,127* | *2,416* | *2,500* | | | | | | *1.5* | | | |
| *World - oecd/fao proj. (excl. biofuels)* | | *2,043* | *2,244* | *2,325* | | | | | | *1.2* | | | |
| Developing Countries - AT data & Proj. | 1,026 | | 1,304 | | 1,567 | 1,799 | | | | | 1.6 | 1.2 | 0.7 |
| *Developing - CBS data* | *1,026* | *1,205* | | | | | *2.8* | *1.8* | *2.3* | | | | |
| *Developing - oecd/fao Proj.* | | *1,192* | *1,327* | *1,374* | | | | | | *1.3* | | | |
| Developed Countries - AT data & Proj. | 859 | | 985 | | 1,112 | 1,212 | | | | | 0.9 | 0.8 | 0.4 |
| *Developed - CBS data* | *861* | *942* | | | | | *0.6* | *0.0* | *1.3* | | | | |
| *Developed- oecd/fao proj.* | | *935* | *1,088* | *1,126* | | | | | | *1.7* | | | |
| *Developed - oecd/fao proj. (excl. biofuels)* | | *855* | *920* | *955* | | | | | | *1.0* | | | |
| **NET IMPORTS** | | | | | | | | | | | | | |
| Developing Countries - AT data & Proj. | 112 | | 168 | | 232 | 297 | | | | | | | |
| *Developing - CCBS data* | *110* | *121* | | | | | | | | | | | |
| *Developing - oecd/fao Proj.* | | *122* | *140* | *154* | | | | | | | | | |

** Historical data for cereals use for biofuels going back to 1980 exist only for the USA (www.ers.usda.gov/data/feedgrains/FeedGrainsQueriable.aspx )*

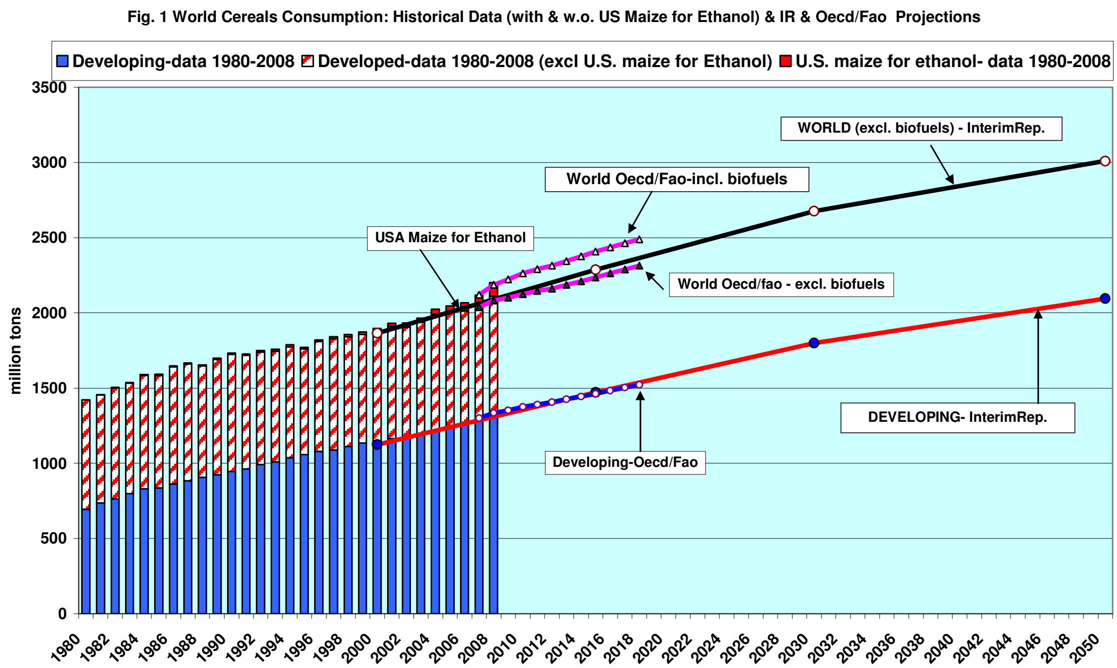


Fig. 1 World Cereals Consumption: Historical Data (with & w.o. US Maize for Ethanol) & IR & Oecd/Fao Projections
Developing-data 1980-2008
Developed-data 1980-2008 (excl U.S. maize for Ethanol)
U.S. maize for ethanol- data 1980-2008
million tons
WORLD (excl. biofuels) - InterimRep.
World Oecd/Fao-incl. biofuels
USA Maize for Ethanol
World Oecd/fao - excl. biofuels
DEVELOPING- InterimRep.
Developing-Oecd/Fao

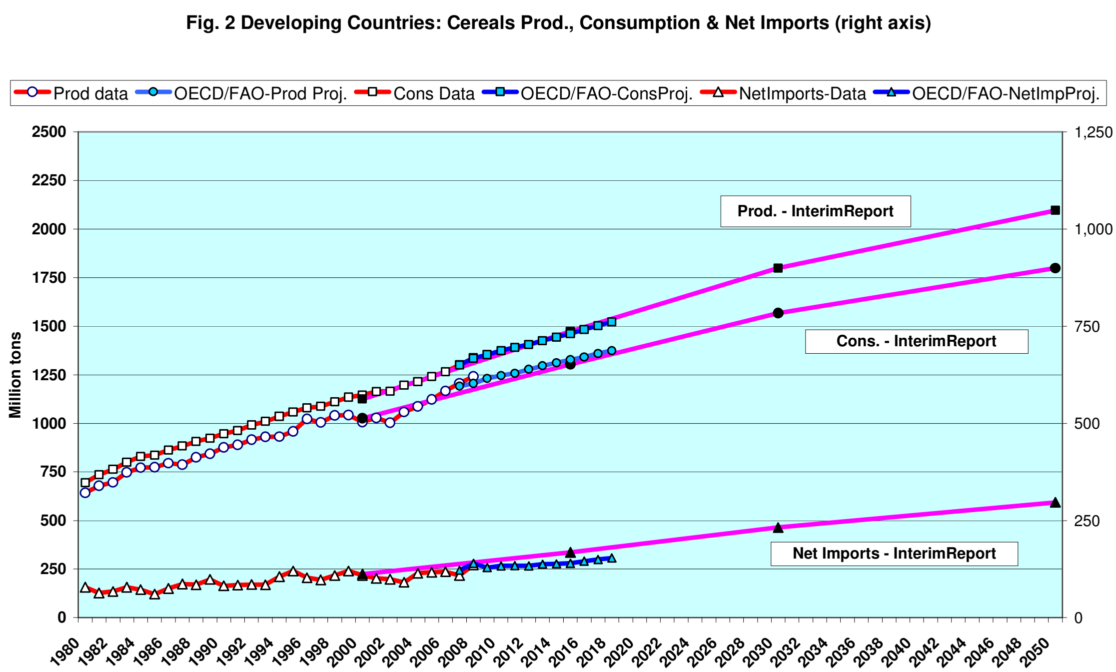
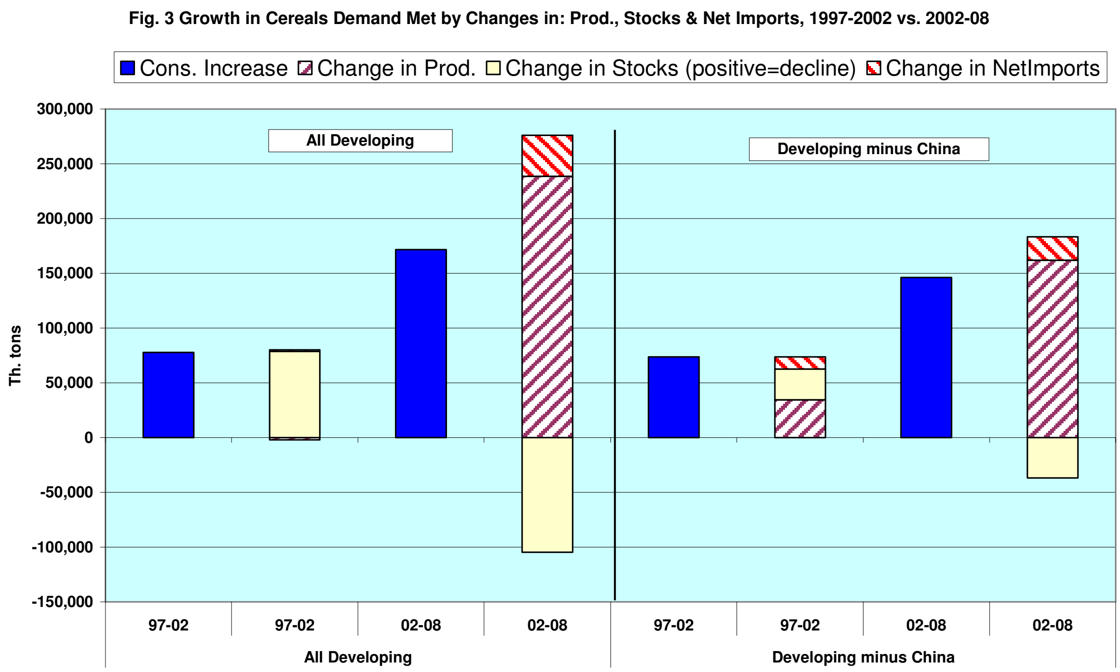


Fig. 2 Developing Countries: Cereals Prod., Consumption & Net Imports (right axis)
Prod data
OECD/FAO-Prod Proj.
Cons Data
OECD/FAO-ConsProj.
NetImports-Data
OECD/FAO-NetImpProj.
Million tons
Prod. - InterimReport
Cons. - InterimReport
Net Imports - InterimReport




## 2.2 Meat

### *Consumption, Developing Countries*

In the Interim Report we had emphasized that the fast growth of meat consumption in the developing countries that had occurred in 1980s and the 1990s was reflecting predominantly developments in China and a few other countries (e.g. Brazil, *Interim Report*, Table 3.7). We had projected that such growth was bound to slow down as these countries reached mid-high levels of per capita consumption. Other developing countries would experience faster growth than in the past, but that would not be sufficient to sustain the growth of consumption in the developing countries and the world as a whole at the high rates of the preceding two decades. Is the slowdown happening?

Table 2 shows that the deceleration in the developing countries is taking place: from over 5 percent p.a. in the 80s and 90s to 3.1 percent in the first 7 years of the projection period and more or less on target to meet the 2.8 percent projected for the period to 2015. The OECD/FAO projections foresee a growth rate of 2.6 percent p.a. from 2006/08-2018, in line with the 2.8 percent p.a. of the IR from 99/01-2015. They project per capita consumption to rise slowly from 29 kg in 2006/08 to 33 kg in 2015, the same as in the IR for that year.

### *Consumption, Developed Countries*

In contrast, meat consumption in the developed countries has been growing faster than anticipated in the IR. Per capita consumption rose from 75 kg in 99/01 to 80 kg in 2006/08. In the OECD/FAO projections it rises further to 85 kg in 2015 and on to 87 kg in 2018. This contrasts with the IR projection of 83 kg for 2015 and 95 kg in 2050. The overshooting is wholly due to the strong rebound of consumption in the Transition countries (the former USSR and Eastern Europe) in the early years of the projection period after the slump of the 1990s. Their per capita consumption rose from 46 kg in 99/01 to 57 kg in 2006/08, a level the IR had projected to be reached at a later year. Clearly, account must be taken of this fact in any further discussion of the livestock sector prospects. Needed revisions would raise their consumption in the medium term. However, the key issue here is whether this would alter in any significant way the longer term prospects as depicted in the IR. Think of it this way: these countries' consumption of 23 mt of meat in 2006/08 accounts for 8.5 percent of the world total. Their population is on the decline (from 404 m. in 2007 to 346 m. in 2050). Therefore, even if they continued their rapid growth of meat consumption to reach the average of the developed countries (some 95 kg per capita by 2050), they would add to world consumption another 9 mt (or 2 percent) to the 465 mt the IR had projected for

2050, not a significant change. Therefore, the key issue remains whether the developing countries, with their growing weight in world population and meat consumption, are likely to make faster progress than we had projected (from 26.7 kg per capita in 99/01 to 44 kg in 2050). So far the growth is on the projected trajectory with per capita consumption having reached 29 kg in 2006/08. As noted, the OECD/FAO projections indicate 33 kg for 2015 and 34 kg in 2018.

*Consumption, World*

The growth of world meat consumption has been slowing down, from 3.3 percent p.a. in the 80s and the 90s to 2.3 percent p.a. from 99/01-2006/08. The IR projects 2.0 percent p.a. for 99/01-2015 and further declines in growth in the subsequent projection periods. The OECD/FAO projections have 1.9 percent p.a. from 2006/08-2018, i.e. the acceleration caused by the rebound of consumption in the Transition countries in recent years is not maintained. Overall, therefore, the IR projections of world meat consumption can be considered as an acceptable longer term outlook in the light of developments to date, at least for the global totals.

*Production*

The production projections mirror those of consumption, given that net trade is a very small fraction (less than one percent) of production/consumption for the large country aggregates considered here. Therefore, the above commentary on the consumption magnitudes applies also to those of production.

**Table 2** **Meat (Bovine, Ovine, Pig, Poultry): IR Data to 2001 & Projections vs. Revised CBS Data to 2008 & Oecd/Fao Proj. to 2018**

| | **Million Tons (carcass weight)** | | | | | | **Growth rates - % p.a.** | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **1999/2001** | **2006/08** | **2015** | **2018** | **2030** | **2050** | 81-90 | 90-00 | 99/01-06/08 | 06/8-2018 | **99/01-2015** | **2015-30** | **2030-50** |
| **CONSUMPTION** | | | | | | | | | | | | | |
| World -IR data & Projections | 228 | | 305 | | 380 | 463 | | | | | 2.0 | 1.5 | 1.0 |
| *World - CCBS data* | 230 | 270 | | | | | 3.3 | 3.3 | 2.3 | | | | |
| *World - oecd/fao proj.* | | *267* | *312* | *328* | | | | | | *1.9* | | | |
| Developing Countries - IR data & Proj. | 127 | | 191 | | 258 | 334 | | | | | 2.8 | 2.0 | 1.3 |
| *Developing - CCBS data* | 128 | 159 | | | | | 5.2 | 6.5 | 3.1 | | | | |
| *Developing - oecd/fao proj.* | | 157 | 195 | 208 | | | | | | *2.6* | | | |
| Developed Countries - IR data & Proj. | 101 | | 113 | | 123 | 130 | | | | | 0.8 | 0.5 | 0.3 |
| *Developed - CCBS data* | 102 | 112 | | | | | 2.3 | 0.4 | 1.3 | | | | |
| *Developed - oecd/fao proj.* | | 110 | 117 | 120 | | | | | | *0.8* | | | |
| **PRODUCTION** | | | | | | | | | | | | | |
| World -IR data & Projections | 230 | | 306 | | 382 | 465 | | | | | 1.9 | 1.5 | 1.0 |
| *World - CCBS data* | 230 | 271 | | | | | 3.3 | 3.2 | 2.4 | | | | |
| *World - oecd/fao proj.* | | *268* | *312* | *329* | | | | | | *1.9* | | | |
| Developing Countries - IR data & Proj. | 125 | | 190 | | 255 | 332 | | | | | 2.8 | 2.0 | 1.3 |
| *Developing - CCBS data* | 126 | 158 | | | | | 5.1 | 6.2 | 3.3 | | | | |
| *Developing - oecd/fao proj.* | | 156 | 192 | 205 | | | | | | *2.5* | | | |
| Developed Countries - IR data & Proj. | 104 | | 116 | | 126 | 133 | | | | | 0.7 | 0.6 | 0.3 |
| *Developed - CCBS data* | 104 | 113 | | | | | 2.3 | 0.4 | 1.2 | | | | |
| *Developed - oecd/fao proj.* | | 112 | 120 | 124 | | | | | | *0.9* | | | |

### 2.3 Vegetable Oils

The IR (p. 27, 52-58) highlighted the importance of vegetable oils as a fast growing item in the food consumption growth of the developing countries. It projected that such growth would continue for some time (IR Tables 2.7, 3.9). It also highlighted the growing weight of the non-food uses of oils in industry (paints, detergents, lubricants, generally oleochemicals and, increasingly, biodiesel). It projected that world consumption for both food and non-food uses would continue to grow at high rates, though not as high as those of the recent past. To the extent that the historical data on non-food uses included biodiesel, the IR projections must be considered as containing an allowance for biodiesel, though of unknown magnitude. How do the IR projections compare with developments in the current decade and the OECD/FAO projections?

Straightforward comparisons of quantities like those shown earlier for cereals cannot be made for vegetable oils. This is because the CBS data are not of the same specification as those used in the IR analyses (see Box 1). In addition, in the OECD/FAO projections the oilseeds-oils complex is treated as two commodities: "vegetable oil" (the sum of only the four major oils – from soybeans, rapeseed, sunflowerseed, and palm) and "oilseeds" (sum of rapeseed, soybeans and sunflowerseed). It does not cover the other oils and oilseeds (coconut, groundnut, sesame, cottonseed, olive, others), some of which are important in several countries. Therefore, the IR data and projections cannot be compared directly (in terms of quantities of production and consumption) with the data in CBS nor with the OECD/FAO projections. We can at best compare projected growth rates of consumption of vegetable oil only (not of oilseeds) of the IR vs. those of the OECD/FAO exercise, which are not affected significantly by the differences in commodity coverage and specification.

Comparisons of the consumption growth rates are shown in Figure 4. The growth rates in the IR projections for the period 99/01-2015 are generally lower than those of the OECD/FAO projections for 2006/08-18. However, the latter include an allowance for biodiesel. Without it, the OECD/FAO growth rates of consumption are lower than those of the IR. In practice, the IR growth rates are halfway between those of the OECD/FAO projections with biodiesel and those without biodiesel, e.g. the IR world growth rate of 2.7 percent p.a. is halfway between the 3.4 percent of OECD/FAO with biodiesel and 2.2 percent without biodiesel.

As noted, the IR projections contain an unknown component for biodiesel, but it must be small: the use of oils for biodiesel really shot up in the last few years, from under 1 mt in 99/01 to 10 mt in 2006/08 (mostly in the EU and to a lesser extent the United States of America and several developing countries – Argentina, Brazil, Malaysia, Indonesia, Thailand), according to the data used in the OECD/FAO projections. It is noted that the four oils included in the OECD/FAO definition of the commodity "vegetable oils" are the fastest growing ones. Therefore, it is to be expected that the growth rate should be higher in the OECD/FAO projections than in those of the IR which includes also the slower-growing oils. By and large, therefore, the IR projections can be considered an acceptable basis for generating a long term outlook for the sector after adding one or more alternatives for biodiesel use of vegetable oils.

The IR projections indicated growing export orientation of the sector in the developing countries (a growing share of total production going to exports) and a growing import dependence of the developed countries (a growing share of their consumption coming from net imports from the developing countries – Figure 5). The OECD/FAO projections confirm these prospects, though direct comparability of quantities is not possible. The developed countries are increasing their net imports of oils from 8.1 mt (20.4 percent of consumption) in 2006/08 to 16 mt (28.2 percent of consumption) in 2018. At the same time they continue to be net exporters of oilseeds, predominantly soybeans from the United States of America, to the tune of 20.5 mt in 2018, up from 15.5 mt in 2006/08. These net oilseeds exports correspond roughly to 4-5 mt of oil equivalent[14], therefore their net imports of all oils and oilseeds (in oil equivalent) would be some 11-12 mt in 2018 (16 mt minus 4-5 mt). This is higher than the IR projection for 2015 which is 7.2 mt. The difference can be attributed to the higher oil and oilseed imports following the growth of the biodiesel industry in the developed countries.

[14] The bulk of the developed countries oilseed exports are soybeans from the United States of America but also rapeseed and sunflowerseed (mainly Canada, Eastern Europe, Ukraine). Therefore, if we wanted to convert the net oilseed exports of the developed countries to oil equivalent (to obtain a number that can be compared with the definition used in the IR), they would correspond to some 4-5 mt of oil (using an average oil extraction rate near that of soybeans 18-19 percent, but increased to 20-25 percent to account for the higher extraction rates of rapeseed and sunflowerseed, 41-43 percent).

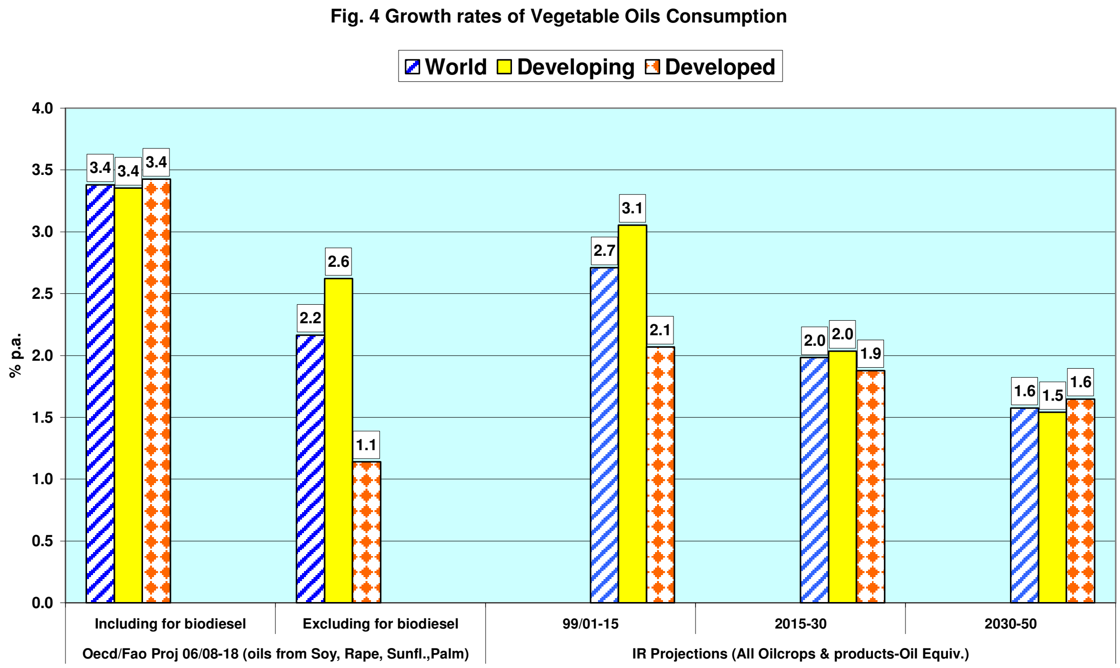


Fig. 4 Growth rates of Vegetable Oils Consumption
World
Developing
Developed
% p.a.
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
3.4
3.4
3.4
2.2
2.6
1.1
2.7
3.1
2.1
2.0
2.0
1.9
1.6
1.5
1.6
Including for biodiesel
Excluding for biodiesel
99/01-15
2015-30
2030-50
Oecd/Fao Proj 06/08-18 (oils from Soy, Rape, Sunfl.,Palm)
IR Projections (All Oilcrops & products-Oil Equiv.)

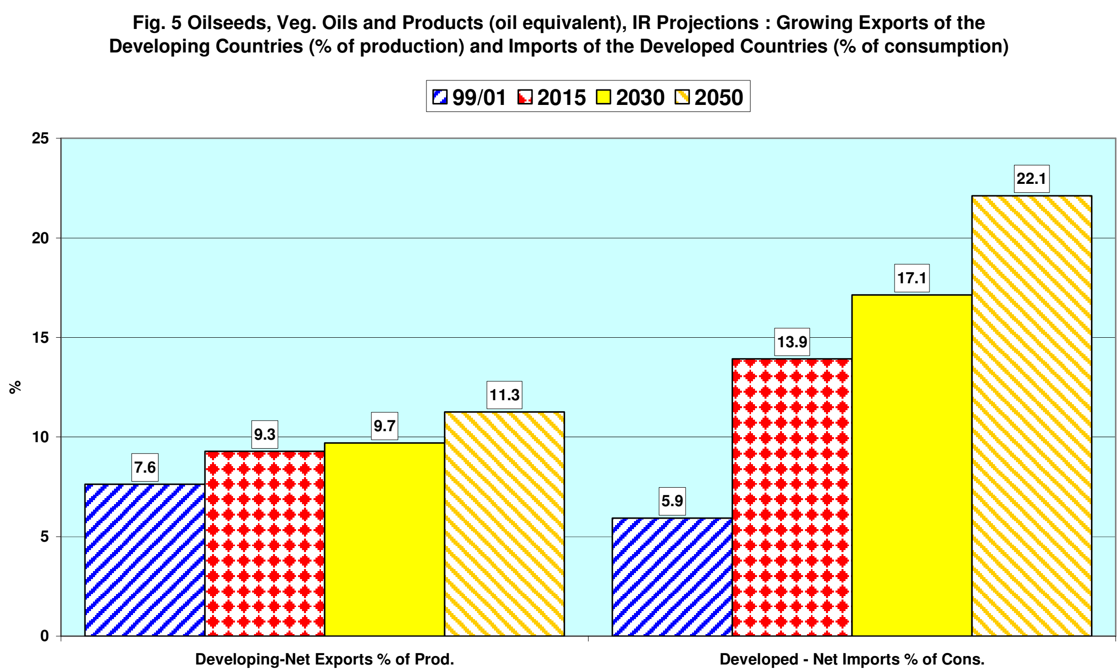


Fig. 5 Oilseeds, Veg. Oils and Products (oil equivalent), IR Projections : Growing Exports of the Developing Countries (% of production) and Imports of the Developed Countries (% of consumption)
99/01
2015
2030
2050
%
25
20
15
10
5
0
7.6
9.3
9.7
11.3
5.9
13.9
17.1
22.1
Developing-Net Exports % of Prod.
Developed - Net Imports % of Cons.

## 3. BIOFUELS: SIGNIFICANCE FOR THE LONG-TERM OUTLOOK

The potential of using crops to produce biofuels had its moment of glory during the recent price surges of both energy and food commodities. At the one extreme biofuels were vilified as causing the food price surges and, occasionally, of being destructive of the environment and the land and water resources. At the other extreme, they were seen as offering great opportunities for boosting farm incomes and energy independence, as well as mitigating adverse environmental effects by reducing the burning of fossil fuels.

With the collapse of the oil prices the debate subsided. These days headlines are more often than not concerned with the woes of the biofuels industry following its rapid expansion during the boom years. The industry is largely kept alive by the mandates and subsidies, with the possible exception of that of sugar ethanol, mainly in Brazil.

Yet, the issue is hardly dead. High energy prices are likely to return (IEA, 2008; Stevens, 2008; McKinsey Global Institute, 2009) and the geopolitical causes driving the quest for energy security are not going away. Add the strength of the farm lobbies and those of the biofuels industry, the continuing relevance of environmental concerns and the prospects of technological change in converting biomass to liquid fuels and we can expect the debate to re-ignite again. It follows that any assessment of long term food prospects cannot ignore the possibility that the expected "normal" slowdown in the growth of demand for agricultural produce (and the underlying claims on agricultural resources and technology development) may not materialize. Therefore, we need one or more projection alternatives accounting for the biofuels effects. This is easier said than done. As noted, with the possible exception of Brazil's sugar ethanol, the use of grains and vegetable oils for biofuels has largely been driven by mandates and subsidies. Therefore, the historical data do not provide an adequate basis from which to glean valid relationships concerning the role of energy/crop relative prices as triggers of demand growth.

Currently, biofuels projections are commonly an integral part of most projections of food and agriculture. The latest attempts in this area which contain (in varying degrees) sufficient detail of the biofuels modules are all medium-term (10 years), not long-term. They include the latest annual issues of the ten-year outlooks by the USDA (2009), FAPRI (2009) and OECD/FAO (2009). The latter provide the most detail, so we use it below to illustrate the orders of magnitude involved. Figures 6 and 7 show the volumes of biofuels (ethanol and biodiesel, respectively) projected to be produced by 2018.

**Fig. 6 Ethanol Production (th. t.), Oecd/Fao Projections**

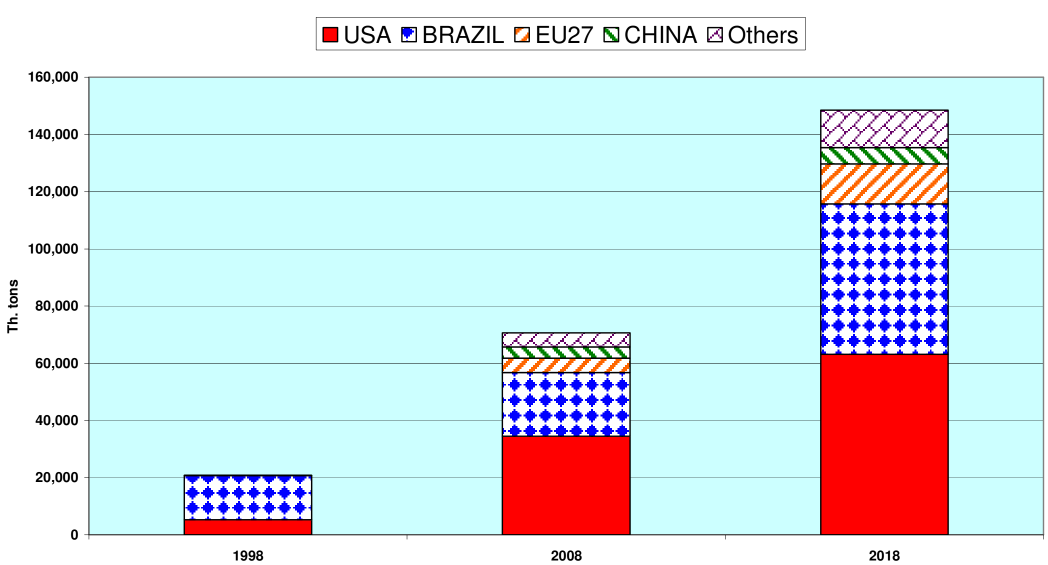
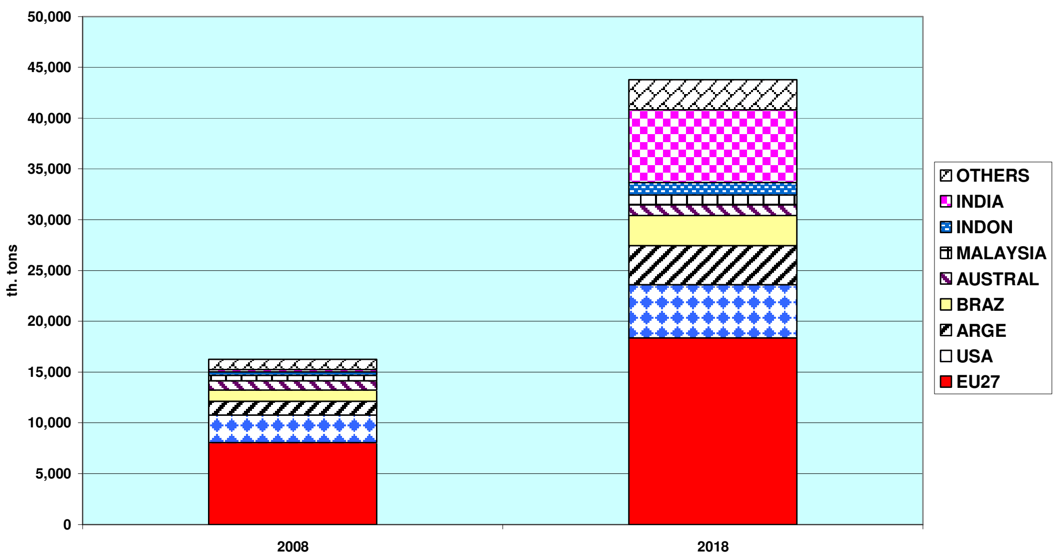


**Fig. 7 Biodiesel Production (th. t.), Oecd/Fao Projections**




Concerning ethanol, world production is projected to just over double from 2008-18, with the United States of America, Brazil and the EU27 being the major players. Both Brazil and the EU would increase their share in the world total. The share of the United States of America would be somewhat reduced (from 43 percent to 37 percent) and will lose its top post to Brazil whose share increases from 34 percent to 39 percent. Biodiesel production is seen as growing even faster than ethanol, by 170 percent in the 10-year period. The EU would continue to hold top place with 42 percent of world production (down from the some 50 percent currently). The great revelation (according to these projections) could be India, with biodiesel production going from very little today to some 7 million tons in ten years, all of it from jatropha, becoming the world's second largest producer with a share of 16 percent. This reflects the mandate of a 20 percent biofuels blend in gasoline and diesel by 2017.

The key issue is, of course, what all this may imply for food security and nutrition. Concretely, would food consumption be lower than it would be without the use of food crops for biofuel production? We cannot be very concrete about this matter without running counterfactual scenarios, which is not practicable at the moment. It is not just a question of whether world consumption of food and feed would be lower because of the price rises caused by, mainly, the biofuels. We can take it for granted that this would be the case, given that diversion of grain to biofuels affects most directly the feed/livestock sector in the developed countries which is more sensitive to price changes than other components of the food system. However, issues of food security and nutrition have to do with the food consumption of those countries that have large proportions of their population undernourished and also large proportions just above the threshold (the MDER – see next section on nutrition). In such cases, food price rises could aggravate the situation of those below the threshold and push some of those above it to the class of undernourished.

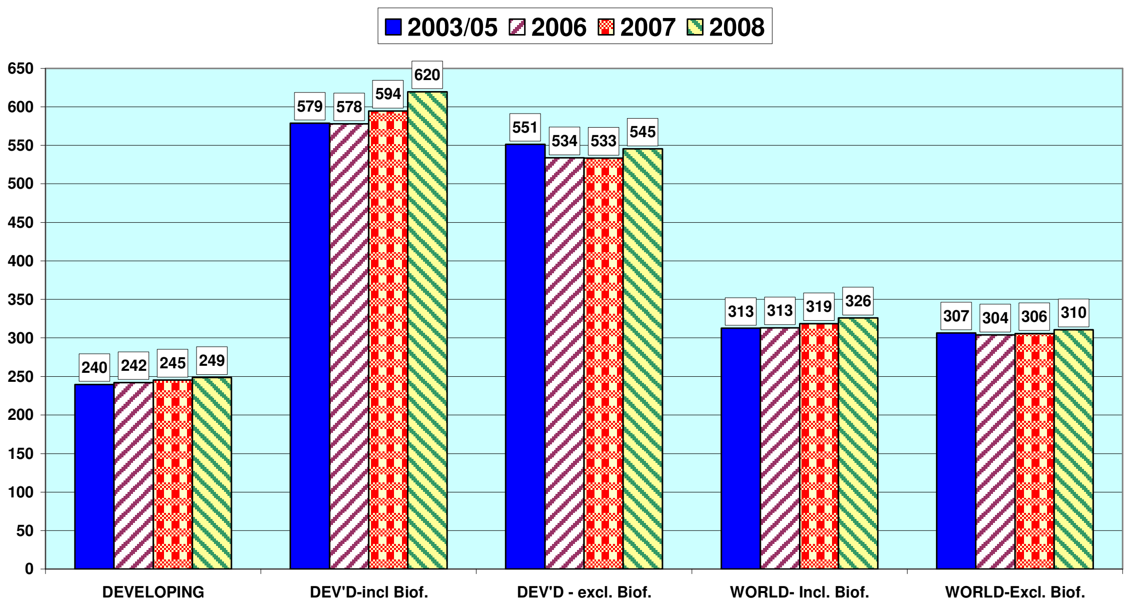
None of the aforementioned ten-year projection studies offers scenarios with and without biofuels[15]. Developments in the last few years of price surges embody information that can help go some way towards answering the question at hand. That is, do they tell us anything about the impact of biofuels on per capita food consumption? And in which country groups? We have seen earlier (Table 1) that some 84 mt of cereals were used for biofuels in the 3-year average 2006/08, 105 mt in 2008 alone. Has this led to a reduction in per capita

[15] A recent IIASA study for the OPEC Fund for International Development (OFID, 2009, Part III, Box 3.4-1) indicates that 66 percent of the additional demand for cereals generated in 2020 by scenarios with growing biofuels use (over and above such use in 2008) would be met by increased production and the rest by reduced consumption of feed (24 percent) and of food (10 percent).

consumption? In the absence of FBS data beyond 2005, we cannot know what happened to the per capita food consumption of all commodities expressed in kcal/person/day. We can only use the CBS data to figure out how per capita consumption of cereals for all uses evolved over the last few years. Figure 8 plots the kg/capita consumption (all uses, with and without the cereals use for biofuels). It is seen that:

1. There have been no declines, but rather small increases, in the per capita consumption of the developing countries (cereals use for biofuels in these countries – some 4 mt in China - is too small, so the entire change can be attributed to non-biofuel uses); and
2. The only declines occurred in the developed countries in 2006-07 in the consumption of food and feed (i.e. all consumption minus the part going to biofuels). With biofuels, their per capita consumption rose significantly.

**Fig. 8 Cereals Consumption (all uses, kg/Cap), including & excluding Use for Biofuels**




Sources: Cereals Cons.: CBS data (03July09); Population: UN (2007); The developing countries are those with estimates of undernourishment in FAO (2008); the developed countries are the rest of the world.

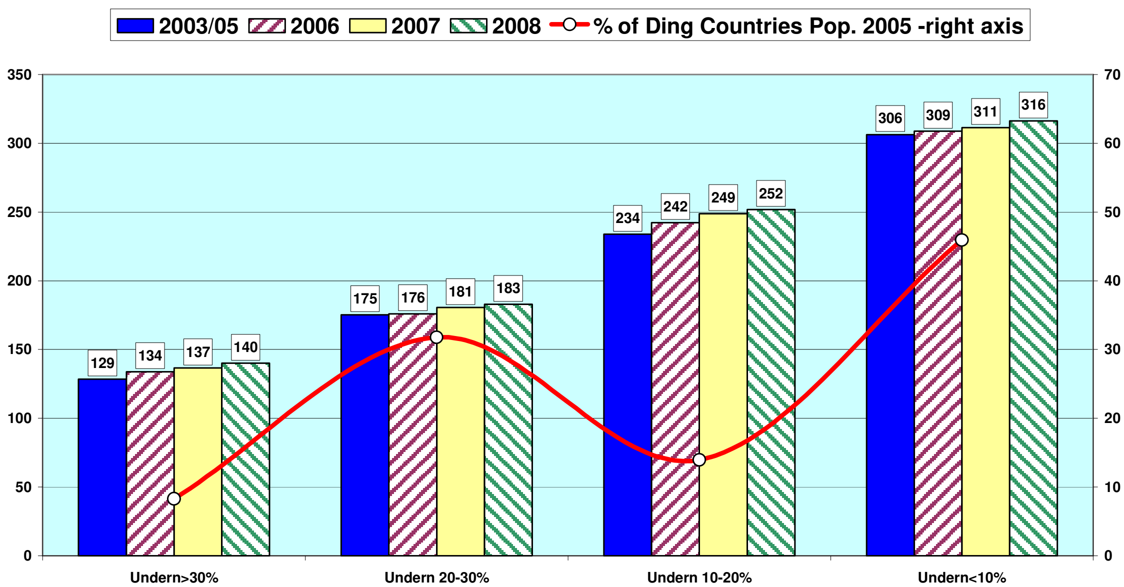
Does this mean that the diversion of cereals to biofuels and the associated price increases did not lead to a reduction in per capita consumption of food and/or to increases in the numbers undernourished in the countries with nutrition problems[16]? We cannot know in the absence of updated FBS data covering all food products. As noted, the risk of deterioration in the nutritional situation in the wake of price surges is highest and most relevant for the countries with low food consumption levels and significant proportions of their population undernourished. To shed some light on this dimension of the issue, an attempt is made in Figure 9 to unfold developments in the per capita consumption of cereals by developing country sub-groups according to their nutritional status in 2003/05 (as given in FAO, 2008). Again, it is seen that no country group suffered a decline. On the contrary, per capita consumption increased in all groups.

Naturally, this is not equivalent to saying that the diversion of grain to biofuels and the associated price rises had no impact on the numbers undernourished: it is possible that, if it were not for biofuels, the per capita consumption of cereals would have improved by more than shown in Figure 8 and 9. Naturally, not the entire amount devoted to biofuels would have been available for food and feed: part of this amount would simply not have been produced since the high prices were to a large measure responsible for the rebound in world cereals

[16] Really, the relevant question is whether per capita consumption is less than it would have been in the absence of the price surges. It is also noted that the numbers undernourished (though not the percent of population) may increase even when per capita consumption does not decline and even increases a little. This can happen because of population growth.

production in both 2007 (+5.4 percent) and 2008 (+7.3 percent). As noted, the IIASA analysis for the OFID suggests that, in the projection period to 2020, some two thirds of the cereals going to biofuels could come from increased production and the balance from reduced consumption of food and, mainly, feed[17].

**Fig. 9 Developing Countries: Cereals Consumption (all uses, kg/Cap) by Status of Undern. in 2003/05**



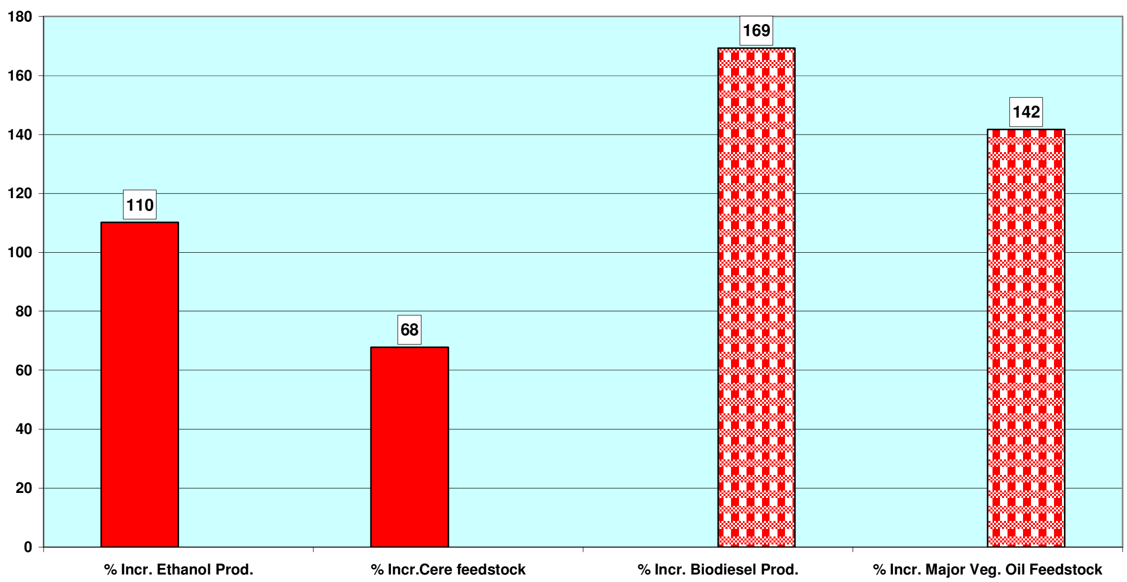

Sources: Undern. Status: FAO (2008); Cereals Cons.: CBS data (03July09); Population: UN (2007); The developing countries are those with estimates of undernourishment in FAO (2008)

The above mentioned increases of biofuels production in the OECD/FAO 10-year projections (Figure 6, 7) imply further increases in the demand for the feedstock crops we presented earlier (cereals and vegetable oils). Naturally, not all additional ethanol will be produced from cereals and not all biodiesel will come from the four major vegetable oils covered in the OECD/FAO analyses. Even without resorting to feedstocks of non-food crop biomass (second generation biofuels), byproducts (e.g. molasses) and food crops other than cereals (mainly sugar cane, sugar beet, cassava, etc) and fats other than the major oils (e.g. tallow, coconut oil, etc) will be contributing a share to biofuels, perhaps a growing one – e.g. as implied by Brazil's increasing share in world ethanol production and India's ascendancy in the biodiesel field based on jatropha. Therefore, the increases in biofuels production will require less than proportional increases in feedstocks from cereals and the major edible vegetable oils (Figure 10). This notwithstanding, in the projections a growing share of world cereals and vegetable oils consumption will be for biofuels, as shown in Figure 11.

What about projections beyond 2018? The above mentioned IFPRI study with projections to 2050 addressed this issue in the following assumption: "We hold the volume of biofuel feedstock demand constant starting in 2025, in order to represent the relaxation in the demand for food-based feedstock crops created by the rise of the new technologies that convert non-food grasses and forest products" (Rosegrant *et al*, 2008, p.11)[18]. If we accepted this assumption we should be thinking of some 200 mt of cereals going to biofuels by 2050 (from the 105 mt in 2008 and the 175 mt in 2018 in the OECD/FAO projections). Assuming two thirds of this additional demand would be coming from increased production (as per above mentioned IIASA estimate for the OFID paper), our original projection of 3010 mt in 2050 (Table 1) would need to be raised to some 3150 mt and food/feed consumption lowered by some 60 mt to 2950 mt.

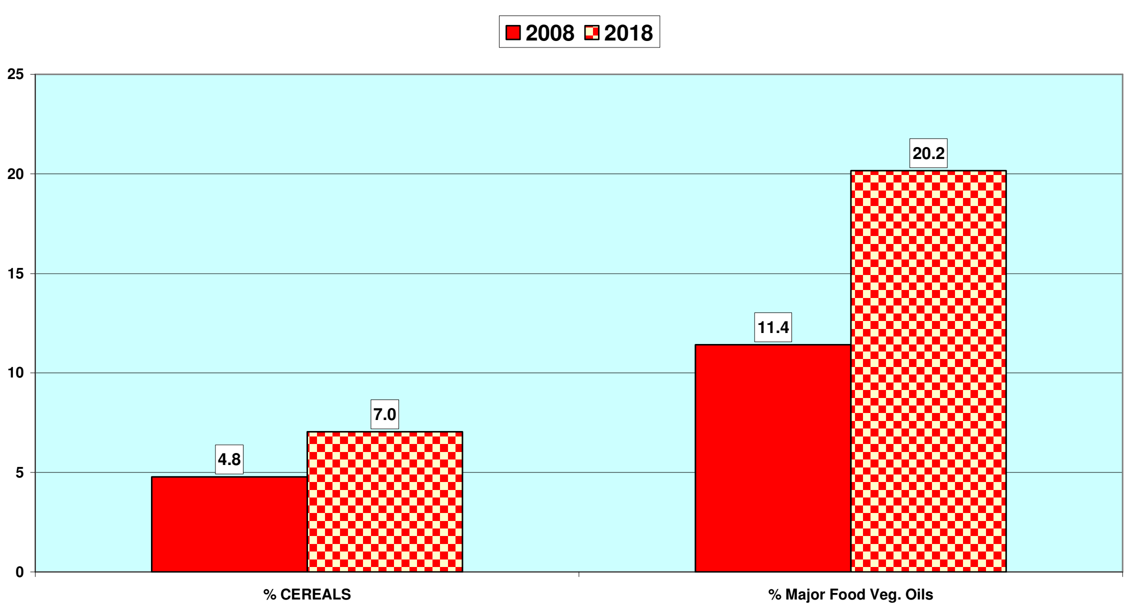
[17] See the companion paper by Fischer (2009) for revised estimates of these percentages.
[18]The eventual advent of second generation biofuels in about two decades, might ease the food-biofuels competition but would not eliminate it, since biomass production for second generation biofuels would still compete for the common land and water resources.

**Fig. 10 Increases in Biofuels Production vs. Increases in Cereals and Veg. Oils Feedstocks, 2008-18**




Source: OECD/FAO (2009)

**Fig. 11 Shares (%) of Cereal and Veg. Oils Biofuel Feedstocks in Aggregate World Consumption**




Source: OECD/FAO (2009). Veg. Oils include those from Soybeans;rapeseed, sunflowerseed, oilpalm. Jatropha not included in Veg. Oils

These are all speculative ballpark numbers and are offered here for the sake of having some orders of magnitude[19]. If they turned out to be approximately correct, world agriculture could perhaps cope with the problem without significantly higher stress over and above that implied by the need to increase cereals production by the some 900 mt projected in the IR, in terms of the required land-irrigation-yield configurations shown in the companion paper by Bruinsma (2009).

[19] A companion paper for this Expert Meeting (Fischer, 2009) will address specifically this issue and hopefully provide a sounder basis for the discussions.

However, things may turn out quite differently if energy prices were to explode and make conversion of food crops to biofuels profitable even without subsidies and mandates. The investment frenzy that underpinned the expansion of the biofuels industry during the recent price surges of petroleum is telling. It may happen again and the energy sector must be seen as competing with the food sector for supplies if it is profitable for it to do so. The latest McKinsey (2009, p. 63) report forecasts for the period 2006-20 an annual biofuels growth rate of 14.4 percent p.a. This is higher than the 10 percent implied by the OECD/FAO projections for the period 2006-18 (sum of ethanol and biodiesel). The latest U.S. Government energy outlook to 2030[20] has world biofuels growth rates in the range 10 percent p.a. (low oil price case) - 14 percent p.a. (high oil price case) from 2006-20. Growth declines drastically in the subsequent decade to 3.7 percent - 4.6 percent p.a.

In conclusion, the food-fuel competition is likely to be with us in the future. Any analysis must address the eventuality that such competition may intensify, with adverse effects on the food security of some countries and population segments: if it happened, the purchasing power of those demanding more energy could easily overwhelm that of the poor demanding food (see further discussion in Schmidhuber, 2006; Alexandratos, 2008). One of the major tasks of any re-make of FAO's long-term projections would be to address this issue, unfold the implications for food security and explore alternatives.

## 4. FOOD CONSUMPTION AND NUTRITION IN THE DEVELOPING COUNTRIES: REVISITING CURRENT ESTIMATES AND THE POSSIBLE FUTURE OUTCOMES

In the Interim Report (Table 2.3) we had projected a gradual rise in per capita food consumption in the developing countries. As a result, the numbers undernourished would be gradually falling, from 811 million in 99/01 to 582 million in 2015. Further declines were projected for 2030 and 2050, with the 1996 World Food Summit target of halving the numbers undernourished by 2015 being within sight shortly after 2030. Is this happening? What do the more recent data show?

As noted, the latest food consumption data from the FBS go to 2005. They indicate that per capita consumption in the developing countries increased between 99/01 and 2003/05, from 2580 kcal/person/day to 2620 kcal (Table 4). One would have expected that the numbers undernourished in 2003/05 would be lower than in 99/01. Yet, the most recent FAO publication *The State of Food Insecurity in the World 2008* (FAO, 2008, hereafter referred to as SOFI08) estimates the numbers undernourished in the developing countries at 823 m. in 2003/05[21], i.e. the numbers increased, no matter that food consumption per capita also increased. This seems to be going against the grain of the arguments made in the IR: that rising per capita consumption and some improvement in the inequality of distribution that goes it would lead to declining undernourishment. It is, of course, quite possible for the numbers undernourished to increase because of population growth, if the increase in per capita kcal is small as is the case here (see above and Table 4). However, we cannot avoid posing the question whether the most recent estimates indicate a real reversal of the trend towards gradually and slowly declining numbers of undernourished or is it just data noise?

Trying to understand what is happening, we note that the data of per capita consumption, population, the minimum dietary energy requirements (MDERs – the threshold for classifying persons as undernourished) and the measure of inequality (coefficient of variation – CV) have all been revised rather drastically. These are the key data and parameters used to estimated undernourishment. They are now different from those in SOFI04 which were used in the preparation of the IR.

For example, the average Kcal/person/day of the developing countries for 99/01 are now 2580 kcal, down from the 2654 used in the IR and in SOFI04. For some countries, the declines are particularly sharp, e.g. Myanmar

[20] U.S. Department of Energy - Energy Information Administration (EIA, 2009), *International Energy Outlook 2009* (May 2009).

[21] The estimates for the developing countries published in SOFI08 are somewhat higher, 832 m. in 2003/05, because now SOFI includes in the developing countries also the Central and Western Asian countries of the former USSR. As noted, in the IR and in earlier SOFI issues these countries were part of the Transition countries group.

(from 2840 to 2160), Ecuador (from 2720 to 2220), Indonesia (from 2910 to 2420), Benin (from 2500 to 2190), etc. Such declines cannot but take a heavy toll of the estimates of undernourished, *ceteris paribus*.

If we had used these revised Kcal in the computation of the IR estimates with all other data equal (population[22], MDERs and CVs) as they were known then, the undernourished would have resulted as 920 m., not 811 m., in the starting 3-year average 99/01 of the IR. Again, using the new kcal of 2003/05 with the population from the UN 02 Assessment (to be compatible with that of the IR for 99/01) and unchanged MDERs and CVs, the undernourished for 2003/05 would have resulted as 910 million a small decline from the estimate for 99/01, not an increase.

The revisions of the other data (population, MDERs and CVs) are responsible for the fact the estimates of undernourishment of SOFI08 imply a small increase rather than a small decline between 99/01 and 2003/05. To better appreciate what is involved we need to look into how and why the data have been so drastically revised.

1. Regarding the population, it is just that the new data from the UN Assessment of 2006 had revised estimates for several countries, which had to be taken on board. This concerned particularly several African countries, e.g. Togo (new estimate for 2000 is 18 percent higher than the old one), Benin (16 percent), Angola (12 percent), Senegal (10 percent), Nigeria (9 percent), Mali (-16 percent), etc.
2. The reasons why the MDERs and the CVs were revised are explained elsewhere (FAO, 2004) and are not repeated here. See also the IR, Box 2.2, for more general discussion of the estimation of the numbers undernourished.
3. Concerning the revisions in food consumption per capita, for some countries the change was predominantly the direct consequence of the population revisions: approx. the same amount of food was now divided by a larger population (e.g. Togo, Benin, Angola, Senegal). In other countries both changes in population and total food supplies were responsible for the changes in per capita consumption (e.g. Nigeria, Mali). At the other extreme, for some countries the change in per capita consumption was almost entirely due to revised estimates of total food consumption in the FBSs (e.g. in Indonesia, Myanmar, Ecuador). Such changes in the data of total food consumption do not come necessarily (or only) from changed total national availabilities of food commodities (production plus imports minus exports plus stock changes). They also reflect changes introduced in the final-use allocations of total availabilities in the course of preparing the revised FBS (allocation between food, feed, stock changes, etc).

### 4.1 Generating a Revised Base Year (99/01) Data Set

The preceding discussion suggests that the IR projections of per capita food consumption (kcal/person/day, given in IR Table 2.1) and the derived projections of undernourishment (IR, Table 2.3) need to be adjusted before they can be compared with the latest situation presented in SOFI08 and provide a basis for making statements about the future course of undernourishment in relation to the present. This is assuming we accept the SOFI08 depiction as representing the reality for the latest year with estimates, i.e. 2003/05. The SOFI08 estimates are based on (a) the revised data of kcal/person/day, (b) the new population data from the U.N. 2006 Assessment and (c) the new MDERs and CVs. We use them to create new estimates of undernourishment in the starting situation of the IR (the base year 99/01). They are shown in Table 3, columns 3 and 9. It is seen that the use of the revised data generate a total estimate of undernourished for 99/01 of 810 m. for the developing countries. It is practically identical to that of the IR (themselves based on those of SOFI04), although regional estimates are somewhat different, no matter that the underlying kcal and parameters have been revised – some of them drastically. Obviously, the impacts of the revisions of the key data and parameters used in the estimation have cancelled one another.

[22] As explained later, changes in per capita food consumption for some countries were predominantly due to the revised data of population. Therefore, using the new consumption data with the unrevised data for the population is not an entirely correct procedure.

**Table 3** **(format: Table 2.3 of the IR) Incidence of undernourishment, developing countries**

| | Percent of Population | | | | | | Million | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 90/92 | 2003/05 | 99/01 | 2015 | 2030 | 2050 | 90/92 | 2003/05 | 99/01 | 2015 | 2030 | 2050 |
| | SOFI 08 | | | | | | SOFI 08* | | | | | |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) |
| **Developing countries** | n/a | **16.3** | **17.0** | **11.3** | **8.1** | **4.8** | **813** | **823** | **810** | **664** | **556** | **370** |
| sub-Saharan Africa | n/a | 30.5 | 32.0 | 22.3 | 13.9 | 7.0 | 169 | 213 | 202 | 204 | 174 | 118 |
| *excl. Nigeria* | n/a | 35.8 | 37.6 | 26.5 | 16.1 | 7.9 | *154* | 200 | 190 | 196 | 165 | 110 |
| Near East / North Afr. | n/a | 7.9 | 8.1 | 6.1 | 5.0 | 3.2 | 19 | 33 | 31 | 31 | 31 | 24 |
| Latin America & Carib. | n/a | 8.3 | 9.7 | 6.9 | 4.4 | 3.1 | 53 | 45 | 50 | 43 | 31 | 24 |
| South Asia | n/a | 21.3 | 21.1 | 13.8 | 10.2 | 5.2 | 283 | 313 | 289 | 238 | 206 | 118 |
| East Asia | n/a | 11.3 | 12.7 | 7.1 | 5.1 | 3.9 | 290 | 219 | 237 | 149 | 115 | 87 |
| *excluding China* | n/a | 15.0 | 17.0 | 12.8 | 8.8 | 5.3 | 112 | 97 | 105 | 93 | 72 | 46 |

*The absolute numbers differ from those published in SOFI08 because the latter includes in the developing countries the Central and Western Asian countries of the former USSR

### 4.2 Adjusting the Projected Food Consumption

Obviously, if we take the SOFI08 estimates for 2003/05 as representing the actual undernourishment situation, we must make adjustments to the projections before we can make any statements how the situation may evolve in the future compared with the present, i.e. 2003/05. Required adjustments must be made to the projected values of (a) the kcal/person/day (to take into account the new starting data of 2003/05), (b) the population of the projection years from the UN 06 Assessment of population prospects which was used to generate the SOFI08 estimates (the population projections of the IR were those of the UN 02 Assessment), and (c) the revised MDERs and CVs.

Ideally, one would want to use the new historical FBS data (available in unpublished form up to 2005) and re-do the whole projections exercise by country and commodity in order to generate the new projected values for kcal/person/day. This is not practically possible at this stage, so shortcuts have to be devised to make adjustments. Box 2 describes the rules used to make the adjustments. These rules were applied directly for each country at the level of kcal/person/day (not by commodity). It is noted again that these adjustments are necessary in order to recognize that the levels of food consumption and the implications for undernourishment depicted in SOFI08 differ from those that formed the basis for the food consumption and undernourishment projections of the IR.

With these adjustments, the revised projections of kcal/person/day are shown in Table 4 (reproducing also Table 2.1 of the IR for comparison). The following comments apply:

1. With the exception of the Near East-North Africa Region, all other developing regions have revised base year data for kcal/person/day lower than in the data used in the IR. The difference is very marked in the East Asia region, particularly if China is excluded from the regional totals (see earlier discussion on the data for Myanmar and Indonesia).
2. These lower starting levels have an impact on the projected values, when the latter are adjusted as indicated above. Although projected per capita levels of the developing countries are lower than in the

IR (by 3.4 percent on average in 2050), the aggregate projected consumption in 2050[23] is virtually the same as that of the IR. This is because the new projected population of U.N.06 is higher than that of U.N.02 (used in the IR), by 3.2 percent. That the new projections of per capita consumption combined with the new population values generate aggregate food demand equal to that of the IR is rather important to note: the aggregate food demand of the IR had been derived as an integral component of the entire configuration of production, consumption (all uses, not only food) and trade. However, while this feature applies to the developing countries aggregate, it may not apply at the level of the individual countries.

3. The result is that in 2050 fewer developing countries than reported in the IR will have reached mid-high levels of per capita food consumption (over 2700 kcal/person/day): 73 countries in these revised estimates accounting for 80 percent of the developing country population in 2050 vs. 85 countries (90 percent of the population) in the IR (see Table 5).

***Box 2. Rules for adjusting the IR food (kcal/person/day) projections***

1. *if the FBS kcal for 2003/05 is lower than that of the IR base year (i.e. $kcal_{03/05} < IR\text{-}kcal_{99/01}$), then the $kcal_{03/05}$ is taken as the base year and the projected values are derived by applying the growth rates of kcal of the IR projections (49 of the 97 developing countries of the IR fall in this category). Thus, for them, $Revkcal_{2015} = kcal_{03/05} \mathbf{x} (1+g)^{11}$, where g is the annual growth rate between 99/01 and 2015 of the kcal in the IR. The $Revkcal_{2030}$ and $Revkcal_{2050}$ are derived applying the same rule, i.e. by applying the respective growth rates of the IR projections on the $Revkcal_{2015}$*
2. *if the FBS kcal for 2003/05 is higher than that of the IR base year, but lower than the kcal for 2015 in the IR projections (i.e. $IR\text{-}kcal_{2015} > Newkcal_{03/05} > IR\text{-}kcal_{99/01}$), the $IR\text{-}kcal_{2015}$ remains unchanged and so do the IR projected kcal for 2030 and 2050 (38 countries in this category).*
3. *If the FBS kcal for 2003/05 is higher than the IR kcal projected for 2015, then $Revkcal_{2015} = Newkcal_{2003/05}$ (10 countries). An upper limit of 3500 kcal is imposed to avoid some countries with very drastic upward revisions in their Kcal exploding towards unrealistically high levels of consumption in the projection years. Cuba is a case in point: it had 2833 kcal in the IR base year 99/01. In the revised data used in SOFI08 it has 3022 kcal for the same year and 3276 kcal for 2003/05.*

[23] This refers to the product (Population ***x*** Kcal/person/day, summed over all developing countries), i.e. the direct food consumption of the different commodities aggregated according to their Calorie content. It does not include uses other than for direct food, e.g. feed, non-food industrial uses, etc. This indicator of total food consumption is distinct from the conventional one (commonly used to make statements about growth of total food consumption or of total agricultural production) where quantities of diverse commodities are aggregated with prices as weights (see discussion of this topic in IR, Box 3.1).

**Table 4 Per capita food consumption (kcal/person/day)**

| | Interim Report Table 2.1 | | | | New data and adjusted Projections | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **99/01** | **2015** | **2030** | **2050** | **99/01New** | **03/05** | **2015** | **2030** | **2050** |
| World | 2789 | 2950 | 3040 | 3130 | 2725 | 2771 | 2884 | 2963 | 3047 |
| Developing countries | 2654 | 2860 | 2960 | 3070 | 2579 | 2622 | 2770 | 2864 | 2966 |
| sub-Saharan Africa | 2194 | 2420 | 2600 | 2830 | 2128 | 2167 | 2319 | 2494 | 2708 |
| *- excluding Nigeria* | *2072* | *2285* | *2490* | *2740* | *2016* | *2061* | *2206* | *2406* | *2643* |
| Near East / North Africa | 2974 | 3080 | 3130 | 3190 | 2991 | 2995 | 3072 | 3134 | 3197 |
| Latin America & Carib. | 2836 | 2990 | 3120 | 3200 | 2798 | 2899 | 2953 | 3084 | 3151 |
| South Asia | 2392 | 2660 | 2790 | 2980 | 2334 | 2344 | 2532 | 2656 | 2843 |
| East Asia | 2872 | 3110 | 3190 | 3230 | 2764 | 2839 | 3034 | 3112 | 3144 |
| *- excluding China* | *2698* | *2835* | *2965* | *3100* | *2475* | *2538* | *2614* | *2740* | *2870* |
| Industrial countries | 3446 | 3480 | 3520 | 3540 | 3429 | 3462 | 3501 | 3548 | 3569 |
| Transition countries | 2900 | 3030 | 3150 | 3270 | 2884 | 3045 | 3043 | 3159 | 3283 |

**Table 5 Population living in developing countries with given per caput food consumption (million)[1]**

| | | **IR Table 2.2** | | | **Revised** | | |
|---|---|---|---|---|---|---|---|
| **Kcal/person/day** | | **1999/01** | **2030** | **2050** | **2003/05** | **2030** | **2050** |
| <2200 | Population (m.) | 584 | 29 | | 515 | 217 | |
| <2200 | Aver. Kcal | 2001 | 2060 | | 1928 | 2087 | |
| <2200 | No Countries | 32 | 2 | | 32 | 6 | |
| | | | | | | | |
| 2200-2500 | Population (m.) | 1537 | 785 | 128 | 2087 | 785 | 381 |
| 2200-2500 | Aver. Kcal | 2403 | 2380 | 2460 | 2365 | 2368 | 2367 |
| 2200-2500 | No Countries | 26 | 17 | 3 | 26 | 20 | 9 |
| | | | | | | | |
| 2500-2700 | Population (m.) | 201 | 510 | 618 | 368 | 2575 | 1148 |
| 2500-2700 | Aver. Kcal | 2547 | 2605 | 2625 | 2616 | 2653 | 2632 |
| 2500-2700 | No Countries | 14 | 23 | 12 | 13 | 26 | 20 |
| | | | | | | | |
| 2700-3000 | Population (m.) | 1925 | 2336 | 1622 | 1372 | 801 | 3035 |
| 2700-3000 | Aver. Kcal | 2933 | 2835 | 2870 | 2987 | 2854 | 2856 |
| 2700-3000 | No Countries | 16 | 31 | 42 | 14 | 25 | 35 |
| | | | | | | | |
| >3000 | Population (m.) | 484 | 3049 | 5140 | 735 | 2495 | 3185 |
| >3000 | Aver. Kcal | 3174 | 3280 | 3200 | 3163 | 3309 | 3262 |
| >3000 | No Countries | 14 | 29 | 45 | 17 | 25 | 38 |
| | | | | | | | |
| All Developing | Population (m.) | 4731 | 6709 | 7509 | 5077 | 6873 | 7748 |
| All Developing | Aver. Kcal | 2654 | 2960 | 3070 | 2622 | 2864 | 2966 |
| All Developing | No Countries | 102 | 102 | 102 | 102 | 102 | 102 |
| [1]Only countries with Food Balance Sheets | | | | | | | |

### 4.3 Revised Estimates of Undernourishment in the Future

The implications of the changes indicated above for undernourishment in the future are unfolded in Table 3. The following comments apply:

1. SOFI08 indicated that the numbers undernourished in the developing countries increased from 90/92-2003/05, although the percent of the population affected declined. We saw above that the same applies to changes in the period 99/01-2003/05. However, we noted that revisions in the data of kcal/person/day alone would have produced a small decline, not an increase. It is the application of the whole package of data and parameter revisions that generates a small increase. Should we take this as indicating that the problem is getting worse rather than improving towards the WFS target of halving absolute numbers by 2015 (from those in 90/92)? We can only note that the increase in the estimate of the absolute numbers is small and may well not be significant, given the data noise.
2. Comparing the new projected numbers of undernourished in Table 3 with those in table 2.3 of the IR, it is evident that projected undernourishment is now higher, both in absolute numbers and as percent of the population. Concerning the higher percentage of the population, it is the result of lower projected per capita kcal (Table 4). The impact is reinforced for the absolute numbers because now the projected population of the developing countries (from UN 06, shown in Table 5) is higher.
3. The revised projections indicate a slow decline in undernourishment. However, in the IR the rate of decline was such that the achievement of the WFS could be within reach shortly after 2030. In the revised estimates, the achievement of the target is shifting further into the future – to just before 2050.

## 5. CONCLUSIONS

In this paper we examined whether the long-term projections to 2050 in the FAO Study (prepared in the years 2003-05 from historical data to 2001 and base year 99/01), were still valid as predictions (for selected broad country- and commodity-aggregates) of what may be in store in world food and agriculture to mid-century. We tested the projections against (a) actual outcomes, as far as data permitted, in the first eight years of the projection period (to 2008), and (b) against the just completed 10-year projections 2009-2018 of OECD/FAO, both with and without the quantities used as biofuels feedstocks. We concluded that, on both counts and disregarding biofuels, the Study's projections are still broadly valid at the level of the aggregates considered.

The advent of biofuels requires a fresh look at the long-term picture. The existing medium-term biofuel production projections and, in some cases, also of the corresponding crop quantities to be used as feedstocks, indicate that further growth is in prospect, though not at the very high rates of the last few years. The quantities of cereals by which, in these projections, world aggregate consumption would be higher because of biofuels would be still relatively modest (7 percent of world consumption in 2018, up from the current 4.8 percent – Figure 11), much of which will likely come from increased production over and above what it would be without biofuels. However, the potential exists for biofuels to be a major disruptive force conditioning agricultural futures because of the growing integration of the energy and agriculture markets. This is a theme which, together with the possible impact of climate change, must inform all future attempts to speculate about long-term futures of world food and agriculture.

We have also examined the Study's projections of food consumption and the numbers undernourished in the developing countries in the light of some drastic revisions in the historical data and parameters used to compute such numbers, as well as in the projected populations. We had to adjust the projected food consumption levels to account for such revisions and make possible comparability of the projections with the latest published estimates (in SOFI08) of per capita consumption and numbers undernourished. These adjustments indicate that rate at which the numbers undernourished were projected to decline, slow and inadequate as it was in the Study's projections, may turn out to be even slower. Achievement of the 1996 World Food Summit target of halving the numbers undernourished in the developing countries by 2015 (from that in 1990/92) may recede well further into the future.

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## APPENDIX

| Table A1. Developing Countries with Cereals Production Growth > 4.0% p.a., 99/01-2006/08* | | | | | | |
|---|---|---|---|---|---|---|
| | Th. tons | | | % p.a. | | |
| | 89/91 | 99/01 | 06/08 | 80-90 | 90-00 | 99/01-06/08 |
| Sierra Leone | 353 | 181 | 913 | 0.2 | -7.2 | 26.0 |
| Iraq | 2,456 | 1,379 | 3,471 | 2.8 | -9.0 | 14.1 |
| Paraguay | 787 | 1,236 | 2,531 | 6.8 | 4.1 | 10.8 |
| Guinea | 521 | 955 | 1,888 | 0.0 | 7.9 | 10.2 |
| Afghanistan | 2,645 | 2,311 | 4,493 | -3.8 | 0.8 | 10.0 |
| Algeria | 2,481 | 1,871 | 3,337 | -1.2 | -4.4 | 8.6 |
| Chad | 647 | 1,103 | 1,952 | 4.6 | 5.0 | 8.5 |
| Ethiopia&Eritrea | 6,370 | 8,858 | 15,378 | 1.7 | 4.0 | 8.2 |
| Cambodia | 1,649 | 2,740 | 4,663 | 8.6 | 6.3 | 7.9 |
| Madagascar | 1,779 | 1,910 | 3,183 | 1.9 | 0.4 | 7.6 |
| Uruguay | 1,101 | 1,568 | 2,600 | 2.1 | 5.8 | 7.5 |
| Morocco | 7,452 | 3,478 | 5,649 | 8.7 | -5.1 | 7.2 |
| Mali | 1,999 | 2,350 | 3,578 | 7.1 | 2.3 | 6.2 |
| Niger | 1,898 | 2,690 | 4,093 | 0.4 | 2.9 | 6.2 |
| Myanmar | 9,110 | 14,002 | 20,934 | -0.2 | 3.8 | 5.9 |
| Sudan | 2,918 | 3,988 | 5,818 | -1.3 | 2.0 | 5.5 |
| Venezuela | 1,834 | 2,565 | 3,722 | 5.6 | 2.6 | 5.5 |
| Iran | 12,248 | 13,224 | 19,139 | 3.8 | 0.0 | 5.4 |
| Zambia | 1,461 | 1,137 | 1,615 | 6.6 | 0.3 | 5.1 |
| Brazil | 34,910 | 46,873 | 65,483 | 2.8 | 2.5 | 4.9 |
| Yemen | 700 | 689 | 958 | 0.4 | 0.3 | 4.8 |
| Tanzania | 3,897 | 3,826 | 5,311 | 3.8 | 0.8 | 4.8 |
| Angola | 297 | 546 | 754 | -2.5 | 7.1 | 4.7 |
| Philippines | 10,781 | 12,732 | 17,312 | 3.3 | 1.0 | 4.5 |
| Burkina Faso | 1,961 | 2,660 | 3,613 | 6.2 | 1.9 | 4.5 |
| Nigeria | 16,896 | 20,045 | 27,223 | 10.4 | 2.1 | 4.5 |
| El Salvador | 764 | 781 | 1,055 | 2.1 | -0.4 | 4.4 |
| Bolivia | 801 | 1,142 | 1,541 | 2.4 | 3.3 | 4.4 |
| Malawi | 1,543 | 2,347 | 3,096 | 1.1 | 7.1 | 4.0 |
| **Sum Above** | **132,257** | **159,187** | **235,303** | **3.4** | **1.7** | **5.7** |
| **Other Developing** | **737,239** | **866,952** | **969,742** | **2.7** | **1.8** | **1.6** |
| **All Developing** | **869,496** | **1,026,138** | **1,205,045** | **2.8** | **1.8** | **2.3** |
| *Only countries with 2006/08 Production>500 th. tons | | | | | | |

# ANNEX

## WORLD AGRICULTURE: TOWARDS 2030/50 – INTERIM REPORT (FAO, 2006)

## EXCERPT FROM CHAPTER 1 - OVERVIEW

### 1.2 Main findings

***Continued growth of world agriculture even after the end of world population growth***

The main reason is that zero population growth at the global level will be the net result of continuing increases in some countries (e.g. by some 31 million annually in 2050 in Africa and South and Western Asia together) compensated by declines in others (e.g. by some 10 million annually in China, Japan and Europe together)[24]. Nearly all the further population increases will be occurring in countries several of which even in 2050 may still have inadequate food consumption levels, hence significant scope for further increases in demand. The pressures for further increases of food supplies in these countries will continue. Much of it will have to be met by growing local production or, as it happened in the past and is still happening currently, it may not be fully met – a typical case of production-constrained food insecurity. The creation of slack in some countries with declining population (e.g. the transition economies, when growth of aggregate demand will have been reduced to a trickle - .01 percent p.a. in the final two decades 2030-50) will not necessarily be made available to meet the still growing demand in countries with rising population, e.g. demand growth at 2.0 percent p.a. in sub-Saharan Africa.

In conclusion, zero population growth at the global level will not automatically translate into zero growth in demand and cessation of the building-up of pressures on resources and the wider environment. The need for production to keep growing in several countries will continue to condition their prospects for improved nutrition. In those among them that have limited agricultural potential, the problem of production-constrained food insecurity and significant incidence of undernourishment may persist, even in a world with stationary population and plentiful food supplies (or potential to increase production) at the global level. Nothing new here: this situation prevails at present and it will not go away simply because population stops growing at the global level. Projections to 2050 provide a basis for thinking about this possible outcome.

***Food and nutrition***

The historical trend towards increased food consumption per capita as a world average and particularly in the developing countries will likely continue, but at slower rates than in the past as more and more countries approach medium-high levels. The average of the developing countries, that rose from 2110 kcal/person/day 30 years ago to the present 2650 kcal, may rise further to 2960 kcal in the next 30 years and on to 3070 kcal by 2050. By the middle of the century the great bulk of their population (90 percent) may live in countries with over 2700 kcal, up from 51 percent at present and only 4 percent three decades ago. As in the past, the great improvements in China and a few other populous countries will continue to carry a significant weight in these developments.

However, not all countries may achieve food consumption levels consonant with requirements for good nutrition. This may be the case of some of the countries which start with very low consumption (under 2200 kcal/person/day in 1999/01), high rates of undernourishment, high population growth rates, poor prospects for rapid economic growth and often meagre agricultural resources. There are 32 countries in this category, with rates of undernourishment between 29 percent and 72 percent, an average of 42 percent, Yemen and Niger among them. Their present population of 580 million is projected to grow to 1.39 billion by 2050, that of Yemen from

[24] Other reasons include the likely continuation of changes in the structure of consumption towards more livestock products following growth in incomes and urbanization, particularly in the developing countries.

18 million to 84 million and that of Niger from 11 million to 53 million. Their current average food consumption of 2000 kcal/person/day is actually a little below that of 30 years ago. Despite the dismal historical record, the potential exists for several of these countries to make gains by assigning priority to the development of local food production, as other countries have done in the past. Under this fairly optimistic assumption, the average of the group may grow to 2450 kcal in the next 30 years, though this would still not be sufficient for good nutrition in several of them. Hence the conclusion that reducing undernourishment may be a very slow process in these countries.

Notwithstanding the several countries with poor prospects for making sufficient progress, the developing countries as a whole would record significant reductions in the relative prevalence of undernourishment (percent of population affected). However, these will not be translated into commensurate declines in the numbers undernourished because of population growth. Reduction in the absolute numbers is likely to be a slow process. Numbers could decline from the 810 million in 1999/01 to 580 million in 2015, to 460 million in 2030 and to just over 290 million by 2050. This means that the *number* of undernourished in developing countries, which stood at 823 million in 1990/92 (the 3-year average used as the basis for defining the World Food Summit target), is not likely to be halved by 2015. However, the *proportion* of the population undernourished could be halved by 2015 – from 20.3 percent in 1990/92 to 10.1 percent in 2015 and on to 6.9 in 2030 and to 3.9 by 2050. It is noted that the U.N. Millennium Development Goals (MDG) refer not to halving the numbers undernourished but rather to a target to "halve, between 1990 and 2015, the *proportion* of people who suffer from hunger". In this sense, the MDG goal may be achieved.

Despite this slow pace of progress in reducing the prevalence of undernourishment, the projections do imply considerable overall improvement. In the developing countries the numbers well-fed (i.e. not classified as undernourished according to the criteria used here) could increase from 3.9 billion in 1999/01 (83 percent of their population) to 5.2 billion in 2015 (90 percent of the population), to 6.2 billion (93 percent) in 2030 and to 7.2 billion (96 percent) by 2050. That would be no mean achievement. Fewer countries than at present will have high incidence of undernourishment, none of them in the most populous class. The problem of undernourishment will tend to become smaller in terms of both absolute numbers affected and, even more, in relative terms (proportion of the population), hence it will become more tractable through policy interventions, both national and international.

The progress in raising per capita food consumption to 3000+ kcal/person/day in several developing countries is not always an unmixed blessing. The related diet transitions often imply changes towards energy-dense diets high in fat, particularly saturated fat, sugar and salt and low in unrefined carbohydrates. In combination with lifestyle changes, largely associated with rapid urbanization, such transitions, while beneficent in many countries with still inadequate diets, are often accompanied by a corresponding increase in diet-related chronic Non-Communicable Diseases (NCDs). In many countries undergoing this transition, obesity-related NCDs tend to appear when health problems related to undernutrition of significant parts of their populations are still widely prevalent. The two problems co-exist and these countries are confronted with a "double burden of malnutrition" resulting in novel challenges and strains in their health systems.

***Growth of agriculture and main commodity sectors***

***Aggregate agriculture***: World agriculture (*aggregate value of production*, all food and non-food crop and livestock commodities) has been growing at rates of 2.1-2.3 percent p.a. in the last four decades, with much of the growth originating in the developing countries (3.4-3.8 percent p.a.). The high growth rates of the latter reflected, among other things, developments in some large countries - foremost among them China. Without China, the rest of the developing countries grew at 2.8-3.0 percent p.a. They also reflected the rising share of high value commodities like livestock products in the total value of production: in terms of quantities (whether measured in tonnage or calorie content), the growth rates have been lower (see Box 3.1).

The future may see some drastic decline in the growth of aggregate world production, to 1.5 percent p.a. in the next three decades and on to 0.9 percent p.a. in the subsequent 20 years to 2050. The slowdown reflects the lower population growth and the gradual attainment of medium-high levels of per capita consumption in a growing number of countries. The latter factor restricts the scope for further growth in demand per capita in several countries which had very high growth in the past, foremost among them China. In contrast, developing countries that experienced slow growth in the past (and as result still have low per capita consumption - less than 2700 kcal/person/day) and potential for further growth, should not experience any slowdown but rather some acceleration. Increasingly, world agriculture will have to depend on non-food uses of commodities if growth rates are not to be sharply lower compared with the past. As noted, the biofuels sector may provide some scope, perhaps a significant one, for relaxing the demand constraints represented by the declining rates of increase in human consumption.

***Cereals***: All the major commodity sectors should participate in the deceleration of agricultural growth. The cereals sector (sum of wheat, milled rice and coarse grains) has already been in such downward trend for some time now, with the growth rate having fallen from 3.7 percent p.a. in sixties, to 2.5 percent, 1.4 percent and 1.1 percent p.a. in the subsequent three decades to 2001. In this latter year world production stood at just under 1.9 billion tons. It has grown further since then to some 2 billion tons in 2005 (preliminary estimate). We project increases to some 3 billion tons by 2050 and this would afford some increase in world per capita availability to around 340 kg (for all food and non-food uses), some 10 percent over present levels. It is noted that the current level of per capita consumption (309 kg in 1999/01) is lower than what was achieved in the past mainly due to the sharp declines in the transition economies (the former socialist countries of the USSR and Eastern Europe) in the 1990s. Recovery in their consumption as well as continued growth in the developing countries should raise the world average to levels it had attained in the past (in the mid-80s). A good part of the increase in world cereals consumption should be for animal feed (mostly coarse grains), with the bulk of such consumption increases originating in the developing countries to support the expansion of their livestock production.

The decline in the growth rate notwithstanding, the absolute increases involved should not be underestimated: an increase of world production by another 1.1 billion tons annually will be required by 2050 over the 1.9 billion tons of 1999/01 (or 1 billion tons over the 2 billion of 2005). Achieving it should not be taken for granted, as land and water resources are now more stretched than in the past and the potential for continued growth of yield is more limited.

Not all countries will be able to increase cereals production *pari passu* with their consumption. Therefore, past trends of ever growing net cereal imports of the developing countries should continue and grow to some 300 million tons[25] by 2050 a 2.7-fold increase over the 112 million tons of 1999/01. This is a much lower rate of increase compared with the past when they had grown more than 5-fold in 40 years. The novel element in the projections is that transition economies are transforming themselves from the large net importers of cereals they were up to the early 1990s (net imports of 43 million tons in 1993) to net exporters (18 million tons net exports annual average in 2002-04). Such net exports could increase further in the future and, therefore, the traditional cereal exporters (North America, Australia, the EU and the developing exporters) would not have to produce the full surplus needed to cover this growing deficit.

***Livestock:*** Production and consumption of meat will also experience a growth deceleration compared with the high growth rates of the past, though the milk sector should accelerate, mainly because of growth in the developing countries demand. The growth of the meat sector had been decisively influenced upwards by the rapid growth of production and consumption in China, and to a smaller extent also Brazil. This upward influence on the world totals was counterbalanced in the 1990s by the drastic shrinkage of the livestock sector in the transition economies, leading to a growth rate in the decade of 2.1 percent p.a. vs. 3.1 percent if the transition economies data are excluded from the world totals. These influences will not be present with the same force in the future - with the exception of continued rapid growth of production in Brazil (mainly for export). The decline in the transition economies has already been reversed while the growth of meat consumption in China, which grew from 9 kg per capita to more than 50 kg in the last three decades, cannot obviously continue at the same high rates for much longer (see, however, Chapter 3 for uncertainties concerning the reliability of the livestock data of China).

[25] To 380 million tons if we exclude from the developing countries the traditional exporters among them - Argentina, Thailand and Vietnam.

The rest of the developing countries still has significant scope for growth, given that their annual per capita meat consumption is still a modest 16 kg. Some of this growth potential will materialize as effective demand and their per capita consumption could double by 2050, i.e. faster than in the past. It is unlikely that other major developing countries will replicate the role played by China in the past in boosting the world meat sector. In particular, India's meat consumption growth may not exert anything like the impact China had in the past, notwithstanding its huge population and good income growth prospects. The country may still have low levels of consumption (though significantly above the current 5 kg) for the foreseeable future.

***Vegetable oils***: The sector has been in rapid expansion, fuelled by the growth of food consumption and imports of the developing countries. The growth of the non-food uses (including in recent years for the production of biofuels in some countries) was also a major factor in the buoyancy of the sector, as was the availability of ample expansion potential of land suitable for the major oilcrops - mainly soybeans in South America and the oilpalm in South-East Asia. Indeed, oilcrops have been responsible for a good part of the increases in total cultivated land in the developing countries and the world as a whole. These trends are likely to continue as the food consumption levels of the developing countries are still fairly low and the income elasticity of demand for vegetable oils is still high in most countries. In parallel, the growing interest in using vegetable oils in the production of biofuels may provide a significant boost. In this respect, concerns have been expressed that the rapid expansion of land areas under oilcrops can have significant adverse impacts on the environment, mainly by favouring deforestation. This is just another example of the trade offs between different aspects of sustainability that often accompany development: benefits in terms of reduced emissions of greenhouse gases when biofuels substitute petroleum-based fuels in transport vs. the adverse impacts of land expansion.

***Sugar***: There are a number of features that characterize the evolution of the sector and determine future prospects: (a) rapidly rising food consumption in the developing countries (3.2 percent p.a. in the last 30 years); (b) the emergence of several of them as major net importers (net imports of the deficit developing countries rose from 10 million tons to 29 million tons over the same period); (c) the growing dominance of Brazil as the major low-cost producer and exporter (production rose from 7.5 million tons to 32 million tons[26] and net exports from 1 million tons to 11 million tons over the same period); (d) the growing use of sugar cane as feedstock for the production of biofuels (ethanol, mainly in Brazil, which now uses some 50 percent of cane production for this purpose); and (e) the prospect that after many years of heavy protectionism of the sugar sector and declining net imports in the industrial countries (which turned into net exporters from the mid-80s, mainly due to the protection of the sector in the EU and the substitution of corn-based sweeteners for sugar in the United States of America), the stage may be set for a reversal of such trends and the resumption of growth in their imports.

Many developing countries, including China, have still low or very low sugar consumption per capita (28 countries have less than 10 kg p.a. and another 18 have 10-20 kg). Therefore, the potential exists for further growth in consumption, though it will not be as vigorous as in the past when 60 developing countries had less than 20 kg in 1969/71. Depending on the evolution of petroleum prices, sugar cane use as feedstock for the production of biofuels may keep growing in several producing countries (or those that have the resource potential to become major producers). Already several countries have plans to do so. It is possible that this development would contribute to keeping the growth rate of world aggregate demand (for all uses) and production from declining in line with the deceleration in the demand for food uses.

***Roots, Tubers and Plantains***: These products play an important role in sustaining food consumption levels in the many countries that have a high dependence on them and low food consumption levels overall. Many of these countries are in sub-Saharan Africa. In some countries (e.g. Nigeria, Ghana, Benin, Malawi) gains in production following the introduction of improved cultivars have been instrumental in raising the per capita food consumption levels. There is scope for other countries in similar conditions to replicate this experience. This prospect, together with the growing consumption of potatoes in many developing countries, should lead to a reversal of the trend for per capita food consumption of these products to decline – a trend that reflected largely

[26] Raw sugar equivalent of sugar cane production

the decline of food consumption of sweet potatoes in China. In addition, the potential use of cassava in the production of biofuels (actively pursued in Thailand) would further sustain the demand growth for this sector.

***Agricultural trade of the developing countries***

The growing imports of, mainly, cereals, livestock products, vegetable oils and sugar of many developing countries has resulted in the group of the developing countries as a whole turning from net agricultural exporters to net importers in most years after the early 1990s reaching a deficit of US$ 12 billion in 2000, before recovering in subsequent years to 2004. The recovery of recent years reflected above all the explosive growth of Brazil's agricultural exports, including oilseeds and products, meat, sugar, etc. Without Brazil, the deficit of the rest of the developing countries, already present from the late 1980s onwards, grew further from US$ 20 billion in 2000 to US$ 27 billion in 2004. Their traditional export commodities (tropical beverages, bananas, natural rubber, etc) did not exhibit similar dynamism and for long periods stagnated or outright declined (in value terms), with the exception of the group fruit and vegetables.

The structural factors underlying these trends are likely to continue. The growing food demand in the developing countries will continue to fuel the growth of import requirements of basic foods in many of them, while the scope is limited for growth of consumption and imports of their traditional exportables to the developed countries. If anything, the growing competition among the developing exporters to supply those nearly saturated markets will continue to put pressure on prices (levels and instability) and lead to shifts in market shares at the expense of the weakest exporters among them, as it happened with coffee in recent years. It may happen with sugar if the preferences protecting the weakest developing exporters were to be diminished or outright removed under the thrust of trade reforms. What will be somewhat different from the past is that the traditional dichotomy developed (net importers)-developing (net exporters) will be further blurred: the markets facing the major developing exporters will be increasingly those of the importer developing countries, as it is already happening with commodities such as sugar and vegetable oils.

## 1.3 Conclusions

The slowdown in world population growth and the attainment of a peak of total population shortly after the middle of this century will certainly contribute to easing the rate at which pressures are mounting on resources and the broader environment from the expansion and intensification of agriculture. However, getting from here to there still involves quantum jumps in the production of several commodities. Moreover, the mounting pressures will be increasingly concentrated in countries with persisting low food consumption levels, high population growth rates and often poor agricultural resource endowments. The result could well be enhanced risk of persistent food insecurity for a long time to come in a number of countries in the midst of a world with adequate food supplies and the potential to produce more.

The slowdown in the growth of world agriculture may be mitigated if the use of crop biomass for biofuels were to be further increased and consolidated. Were this to happen, the implications for agriculture and development could be significant for countries with abundant land and climate resources that are suitable for the feedstock crops; assuming, of course, that impediments to biofuels trade do not stand on the way. Several countries in Latin America, South-East Asia and sub-Saharan Africa, including some of the most needy and food-insecure ones, could benefit. Whether and to what extent this will happen is very uncertain, but the issue deserves serious analysis and evaluation. Of particular interest are (a) possible adverse effects on the food security of the poor and the food-insecure if food prices were to rise because of resource diversion towards the production of feedstock crops for biofuels; and (b) the environmental implications of cultivated land expansion into pasturelands and forested areas. As noted, this is a typical case of possible trade-offs between different aspects of the environment and sustainability: benefits from the reduction in greenhouse gas emissions when biofuels substitute fossil fuels in transport and adverse effects from the expansion and intensification of agriculture.

# WORLD AGRICULTURE IN A DYNAMICALLY-CHANGING ENVIRONMENT:
## IFPRI'S LONG-TERM OUTLOOK FOR FOOD AND AGRICULTURE UNDER ADDITIONAL DEMAND AND CONSTRAINTS

**Siwa Msangi and Mark Rosegrant***

## SUMMARY

In this paper, we explore the nature of several key drivers of change in food systems, and examine a number possible entry points for policy intervention, in order to determine their effect on food prices and other market-driven outcomes. Among the drivers of change that we discuss are those of policy-driven growth in biofuel production, which has had a role to play in the rapid increase in food prices, along with other factors. We demonstrate the off-setting impact that supply growth could have on the socio-economic impacts of biofuels, both in terms of price changes, as well as changes in nutrition status. We also look at some evidence that points towards the significant impact that climate change could have on the agriculture and agricultural prices in the future. Combining our quantitative experiments with cited evidence from other studies, we suggest a range of policy interventions that could be instrumental in offsetting the negative impacts of food prices, and helping to promote those benefits in situations where they might exist. Among these suggestions, we encourage increased investments in the agricultural sector, so as to reverse the steadily declining growth of research and development spending and change decades of counter-productive agricultural trade and national-level sector policies.

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## 1. INTRODUCTION

The sharp increases in food prices that have occurred in global and national markets over the last several years, has sharpened the awareness of policy makers and agricultural economic analysts to the stresses facing global food systems and the ecosystems that support them. The rapid increases in prices of key food commodities such as maize, wheat, rice, soybeans - among others - has mirrored the increase in prices of energy products, and has strengthened the perception that energy and agricultural markets are becoming more closely linked (Schmidhuber, 2006). In the last six years, the international market prices of basic grain commodities have more than doubled, whereas the prices of wheat and rice have tripled. While this might represent a different impact upon the consumer price index in various countries, due to the share of these commodities in total consumption – this represents a significant and sharp change in market conditions, nonetheless. While many see the reversal of historically declining real prices of agricultural commodities as an opportunity for the agricultural producers in both developed and developing countries – others remain concerned about the implications of high food prices and increased volatility in food markets on the welfare and well-being of vulnerable populations who consist of mostly net consumers of these products, and who largely reside in the poorest regions of the developing world (Evans, 2008; FAO, 2008).

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During the same period, prices of oil have increased four-fold, and have caused second-round prices effects on all other goods and services that depend significantly on fossil fuels as inputs to production – including agriculture. Looking forward, into the future, a number of researchers project the continued elevation of world prices for agricultural goods above past historical trends, despite a leveling off in the near-term period from the current highs. The medium-term projections generated by the joint OECD-FAO modeling effort show that a prevailing tightness remains in most major agricultural markets, so as to keep price levels significantly above historical trends (OECD-FAO, 2008). The world market price projections of the International Food Policy Research Institute (IFPRI) show that world grain prices will further increase 30-50% before 2050, and that, in the same period, meat prices will increase an additional 20-30% beyond current high levels (von Braun, 2008).

The underlying factors to the rapid increases in food prices are varied – both in nature, and in their relative strength in driving the market dynamics across various commodities. A number factors have been attributed to the rapid increase in food prices, both within the published literature as well as within the press, and range from the rapid increase in first-generation, food-based production of biofuels (Oxfam International, 2008; Runge and Senauer, 2008) to the increase of cereal and meat demand from East and South Asia – or the increase in speculative activity in food markets. Several comprehensive discussions of this issue have appeared in recent literature, and try to assess the relative merit of each of these factors – while also including an overview of the global macro-economic picture, and the relative decline of the dollar, in relation to other currencies (Abbot *et al.*, 2008). The steady decline in the level of cereal stocks, globally, as a result of the private sector taking over the operation of cereals stocks from government, and adopting a more 'just-in-time' management orientation (Trostle, 2008), has also been cited as a factor that has reduced the ability of national governments to stabilize consumer and producer prices (OECD, 2008). Most authors, however, do not isolate a single cause as being to blame for the current world food situation, but cite a complex interaction between several coincident factors.

The challenges and increased stresses that face global food production and distribution systems, in the present economic climate, are particularly acute and pressing for Sub-Saharan Africa, where persistent levels of food insecurity already exist. To illustrate, roughly thirty-three percent of the population of Sub-Saharan Africa lives with insufficient food supplies (FAO, 2005) and an even greater proportion, forty-three percent, lives below the international dollar poverty line (Dixon *et al*., 2001). The constraints that lie in the way of Africa benefiting from higher producer prices of agricultural commodities on the world market are myriad, and include the fact that most of Sub-Saharan Africa's agricultural production relies on rainfed cultivation, and receives lower input levels of improved seed technology and fertilizer applications than other regions. Additionally, the area affected by land degradation within the region is expanding and is thereby causing a decline in soil fertility that reduces yield levels and increases the difficulty in maintaining sufficient production levels, especially when considering the lack of technological innovation and fertilizer use (FAO, 2005).

In this paper, we examine the key environmental, technological and socio-economic drivers that underpin the global world food situation, and evaluate the potential role of alternative policy interventions that might address it. We discuss these policy interventions in terms of the role they can play in enhancing market stability, food security and human well-being, in the face of the increasing stresses that continue to be placed upon global agricultural markets and food systems. We look, specifically, at the role that biofuels might play in raising food prices, and the role that agricultural technology investments might have in counter-acting these effects. Based on this analysis, we conclude with some final recommendations for both policy intervention and further research.

## 2. DRIVERS OF CHANGE IN FOOD SYSTEMS

The upward pressure on key commodity prices that were mentioned in the previous section, can be accounted for due to a number of underlying factors or 'drivers of change' that are diverse in nature. These 'drivers' range from environmental to socio-economic and from slow to fast-moving, affecting outcomes differently in both the short- vs. the long-term. There a number of underlining factors driving the long-term trends in food supply and demand that have also contributed towards a tightening of global food markets during the past decade. These trends are driven by both environmental and socio-economic changes, as well as by agricultural and energy policy, including those encouraging biofuel production from agricultural feedstocks. Figure 1 illustrates the interactions between the various key 'drivers' of change in global food systems, and their linkage to other components of the food economy and to important outcomes of human well-being – such as nutrition. While this schematic is not completely exhaustive of all the major factors of importance, it incorporates the main elements of global environmental and economic change in food production and consumption systems, that we hope to address in this paper.

Socio-economic change, in the form of increasing growth in population numbers and total income, are among the major drivers that change the economic behavior of consumers, in terms of their demand for food and energy products. Urbanization, which is related to these demographic changes, is another factor that also has an impact on consumption patterns and the transformation of consumer preferences for both food, fibre and energy products. These changes in consumption and consumption preferences introduce increased stresses on food and energy systems from the demand side, while other environmental factors might restrain the supply side of food systems from responding readily – as a result of either resource scarcity or degraded land and water quality. Reduced investments in crop and energy technology, over time, could also lead to a longer-term slowdown in the expansion of supply – which eventually leads to higher prices, as demand begins to grow faster.

Taking these factors into account, as they have been described and presented in Figure 1, we see a variety of entry points for policy or technological intervention that present themselves. These offer a menu of options for the policymaker to consider, when deciding how best to cope with the current stresses on food or energy systems, or how to mitigate the severity of such stresses in future. Now, following, we can discuss a few of these various components and drivers of the food system in more detail, as we put them within the context of food and energy supply and demand systems.

### 2.1 Socio-economic factors

Both demographic growth and socio-economic change – in the form of overall income growth, rates of urbanization or changes in the incidence of poverty in the population over time – are key factors that determine the patterns of food consumption and nutrition outcomes that are observed. Since the oil crisis in the 1970s, there has been notable socio-economic progress and growth in the various regions of the world, in terms of human welfare. Despite population growth, the number of malnourished people in developing countries has declined over time – although at various rates. According to the 2006 State of Food Insecurity report (FAO, 2006a), the decrease of 37 million over the period of 1970-1980 was followed by a decrease of almost 100 million over the 1980-1990 – but only followed by a decrease of 3 million in the period since the 1990-1992 period set as a baseline for the 1996 World Food Summit to the present.. Food has become more affordable, as it is now less than half as expensive in real terms as it was in 1960. The decline in cost of food can be attributed to a large increase in food production, where even in per capita terms, the world now produces 40% more food than forty years ago (MA, 2005). Nonetheless, these positive trends might reverse themselves in the future, if the major tipping points of climate change and accompanying degradation of land and water resources are to intensify in future.

The main socio-economic factors that drive increasing food demand are population increases, rising incomes, and increasing urbanization. Global population is set to increase from approximately 6 billion in 1995 to 8 billion in 2025, with over 98 percent of this increase in developing countries, according to the UN medium variant projections (UN, 2004). In addition, 84 percent of the population increase from 1995 to 2025 in developing countries is expected to localize in urban areas. Incomes, measured by GDP per capita, are expected to grow strongly in recently industrialized nations and most rapidly in East Asia and the Pacific, according to the projections of growth used by a number of key policy centers (World Bank, 2007a; UNEP, 2007). Taking the rates that are used in IFPRI's IMPACT model projections (von Braun, 2008), GDP per capita in China is expected to increase 5.2 percent per year from 1995 to 2025, while Republic of Korea, Thailand, and India grow at approximately 4.5 percent per year. In general, growth rates in Asia will be the highest, ranging from 2.1 to 5.2 percent per year, while Eastern European incomes will rise by 4.1 percent per year. On the other hand, rapid population growth in Sub-Saharan Africa is projected to depress per capita growth rates to approximately 0.8 to 1.7 percent per year.

The combination of rising income and urbanization is also changing the nature of diets. Rapidly rising incomes in the developing world has led to the increase in the demand for livestock products. In addition, it has been shown that urbanized populations consume less basic staples and more processed foods and livestock products (Rosegrant *et al.,* 2001). Diets with a higher meat content put additional pressure on land resources for pasture and coarse grain markets for feed, including maize. As a result of these trends, it is predicted that by 2020 over 60 percent of meat and milk consumption will take place in the developing world, and the production of beef, meat, poultry, pork, and milk will at least double from 1993 levels (Delgado *et al.,* 1999).

Increasing urbanization compounds the pressure on adjacent areas to meet the demand of large, concentrated populations. While urbanized areas themselves do not require a large portion of land, the actual the terrestrial and water resources necessary to support the population can overwhelm existing rural-urban linkages. Many developing countries which are generously land-endowed, find it easier to covert forest and other land cover for agricultural production rather than disseminate yield-enhancing technologies – especially where extension services are limited or non-existent. It is estimated that an additional 120 million hectares of cropland will need to be converted to agriculture in order to meet food demands in developing countries over the next 30 years, with seven countries in Latin America and Sub-Saharan Africa providing most of the land potential (FAO, 2006b).

These agricultural land requirement projections assume that 70 percent of food needs will be met through yield enhancements (FAO, 2006b). Yet, agricultural research dedicated to productivity enhancement of staple crops has declined over the years. As the United States and other developed regions have shifted their research focus to reflect consumer preferences for processed, organic, and humane products, the diffusion of more relevant yield enhancing technology in developing countries has slowed (Alston and Pardey*,* 2006). Only one-third of global, public agricultural research in the 1990s was in developing countries, over 50 percent was concentrated in Brazil, China, India, and South Africa (Alston and Pardey*,* 2006). Therefore, better technology diffusion and more public money dedicated to developing country research programs are critical to meet growing food needs.

### 2.2 Environmental drivers

Increases in population and income increase pressure on natural resources to meet domestic, agricultural, and industrial demand. Many large water basins, including the Yellow River and Ganges, are expected to pump relatively less water for irrigation over the next 20 years due to unfavorable competition from other sectors. As a result, irrigated cereal yields in water scarce basins are expected to decline between 11 and 22 percent in 2025 over 1995 levels (Rosegrant et al., 2005).

Climate change and increasing demand for water resources will impact growing conditions, significantly impacting food production in the future. Integrated assessment models of have shown that climate change effects on temperature and rainfall will having positive yield effects in cooler climates, while decreasing cereal yields in low latitude regions—the geographical location of most developing countries (Easterling *et al.,* 2007*)*. Specifically, developing countries will have a 9 to 21 percent decline in overall agricultural productivity due to global warming, while industrialized countries will face a 6 percent decline to an 8 percent increase, depending on the offsetting effects that additional atmospheric carbon could have on rates of photosynthesis (Cline, 2007). As a result of these differentials in predicted production capabilities, some regions will benefit from increases in yield while others will be left to importing an increasing amount of food to meet demand. Fischer *et al.*, (2005) estimate that cereal imports will increase in developing countries by 10 to 40 percent by 2080. While there is a large variation in the prediction, the combined effects of rapid population growth, lower yields, and increasing reliance on trade policy for food imports could leave between an additional 5 to 170 million additional people malnourished in 2080—with up to 75 percent of the total in Africa—depending on the projection scenario (Schmidhuber and Tubiello, 2007). Parry *et al.,* (2005) have shown that the regional variation in the number of food insecure is better explained by population changes than climate impacts on food availability. As a result, economic and other development policy—especially policy pertaining to agricultural research and technology—will be critical in influencing future human well-being.

### 2.3 Policy-based drivers

In addition to the socio-economic and environmental processes which are described above, there are other factors that can help create the kind of "tight" market environment that we have observed in the recent months. These include the decline in cereal stocks and unilateral trade actions by individual countries, as they both restrict supply in the market. For example, world wheat stocks-to-use ratios have declined from over 40% in 1970 to 20% today – below the oil crisis level. Corn stocks-to-use ratios have declines from their peak in their 45% peak on the 1980s to about 12%, a level also previously only seen during the world oil crisis. We have also witnessed increasing levels of private capital invested in grain markets (as well as other commodity markets) in search of portfolio diversification and as a response to the recent poor performance of the stock market. Lastly, unfavorable macroeconomic developments (such as the dollar devaluation) can further complicate the situation for some consumers.

Looking at productivity growth more closely, we find that yield growth rates for major grains have been declining in the last decades (World Bank, 2007b) and have dropped by roughly 50% since their highs during the 1960s and late 1970s. One of the causes of this decline is no doubt a fall in the growth of public agricultural R&D spending, both in the developing and developed world (World Bank, 2007b). On a global level, R&D spending growth has declined 51% in real terms in the two decades since the 1980s, in the developed world, and the developing world has taken a larger share of the world's agricultural research spending than the developed world, since the 1990s (Alston and Pardey, 2006). This is especially troubling since IFPRI projects that future production growth will stem from yield improvements, rather than area expansion, as has been found in past assessments of global agricultural futures, such as the Millennium Ecosystem Assessment (MA, 2005). In fact, some regions of the world, such as East Asia, Europe and North America, will need to increase production even as agricultural area shrinks.

### 2.4 Characterizing the drivers of change

Given the rather complex interplay of factors that have been described both in this paper, as well as in the wider literature, it is useful to try and separate the slower-acting, long-term drivers of change from the faster-moving ones that might have more of an impact in the short-term period. Population growth and income growth tend to act relatively slowly and steadily over time, and evolve in a rather predictable fashion – given the nature of the drivers which underlie demographic and economic growth, and the experience we've observed in the past. There are also long-term shifts in climatic conditions at play, that also tend to unfold more gradually over a period of time – compared to the shorter-term manifestations of climatic variability that might be manifest in weather events that occur within the cyclical progression of seasons. Finally, when considering the catalog of slow-moving changes, we can cite the gradual slowing-down of crop yield growth that has been observed over time, relative to the rate of food demand growth which is occurring, and driven by socio-economic changes. In contrast to these types of slow-moving drivers of change are the faster-moving ones, which can take the form of sudden climatic and environmental shocks that can cause seasonal losses of harvest. While food demand tends not to surge upwards, over short periods of time, we have observed relatively rapid increases in the demand for energy – especially that which is driven by transportation energy needs – which manifests itself in the increasing demand for fossil-based fuels as well as for renewable substitutes such as biofuels. The demand for biofuels, such as ethanol and biodiesel, tends to be strong when fossil-based fuel prices are high, and when national fuel policies push for increased levels of blending to reduce the cost of fuel imports. This has been the case in a number of countries around that world, and is a major determinant in the rapid expansion of biofuel production which has been observed in the past 6 years.

Given the various drivers of change that are cited in both the literature, and in the previous sections, it is worthwhile to consider their characteristics so as to better understand their relative importance in explaining the tightening of market conditions that we have observed in global food markets in recent times. Despite some of the fairly comprehensive overviews and discussions of high food prices – in terms of their causes and consequences – relatively little effort has been made to distinguish between their dynamic characteristics of change, so that their relative importance in explaining short-term versus long-term phenomena can be appreciated. Having such a distinction is helpful, not only in being able to identify the most urgent issues to address first, from a point of view of policy, but also help to identify which types of issues are of a more temporary nature, and which might persist into the future and prevent market and food system characteristics from returning to a stable equilibrium, or which might cause prices to rise even further, later on.

While Figure 1 does show how the various drivers of change interact with each other, and where the critical feedback loops might be – it does not provide us with the type of distinguishing characteristics that can explain short-lived and longer-lived effects on food systems. Figure 2, however, does more to make this distinction, and shows where some key drivers of change lie in relationship to each other, with respect to their dynamic characteristics – which is a combination of the speed with which they act, as well as the degree to which they explain short-term or long-term phenomena. Taking the end of the spectrum that contains both fast-acting drivers that help to explain short term effects, we see that market speculation stands out as a factor that might explain the 'bubbles' that might form in markets, due to expectations about short- to medium-term trends, but which might reverse themselves fairly rapidly on the basis of economic conditions and fast-changing market information. This type of activity has been cited as a factor that explains the spikes that developed in some markets, even contrary to the indicators provided by the supply and demand fundamentals that usually determine price formation (von Braun *et al.*, 2008).

On the other end of the spectrum, relatively slow-moving phenomena that will play a part in determining the long-term evolution of food systems and the performance of the underlying ecosystems that support them, is climate change – which encapsulates the changes in long-term means of temperature, precipitation and even atmospheric content, that impact crop growth potential and the characteristics of key agro-ecological systems. Climate change, as a phenomenon, should be distinguished from effects of climate variability and extreme incidents of weather that are presently made manifest in many regions and which act over a much quicker time scale. These types of weather shocks drive the supply-side of the food equation and lead to sudden drops in output that can push up market prices, whereas sudden surges from the demand side of the equation (like those due to growth in crop-based biofuel production) might tighten market conditions and contribute towards similar price increases.

Other drivers of supply and demand change which operate on a slower-moving trajectory are those of growth in demand for key consumer food products, such as cereal and meat (which also have implications for feed demand), as well as trends for crop yield growth which determine how well the supply side can adjust to increases in demand. Changes in demand for food and fibre products tend not to 'surge' as rapidly as those for energy-intensive products, such as petroleum for transport, but represent a component of food system change that will continue to keep prices at an elevated level into the future, as has been cited by the OECD in their projections of agricultural production and prices to 2017 (OECD-FAO, 2008), as well as for longer-term projections (von Braun, 2008).

### 2.5 Entry points for policy

Given the various drivers of change that we have discussed, above, we might consider several possible entry points for policy intervention, which might address the current global food situation. As is shown in Figure 1, there a number of entry points for intervention that can be considered – both from the supply and the demand side. Looking at the demand side first, we see that policies that govern the use of food-based feedstocks for biofuel production could be altered, such that the overall quantities that come from food and feed sources are substituted for other non-food feedstocks or feedstock conversion technologies. Other policies which might affect direct food and feed use of grains would rely on the alteration of consumer preferences for food products (including meat), and are not as straightforward to address within the analytical framework we will discuss in this paper. Therefore, our attention will focus on the use of food crops in biofuel production.

From the supply side, there are a number of interventions which we will consider. The first is to boost the output of cereals by raising yield levels over time – through policies that accelerate the improvement of crop technologies, such that the higher growth rates of yield are realized. This can be done directly through improved seed technologies, which might enhance the productivity and hardiness of plant varieties, or through the expansion of area under irrigated production, which has a higher yield than rainfed alternatives, typically. Improved seed technologies can even reduce the loss in productivity that occurs when irrigated crops become water-logged or subject to increased salinity and submergence – thus allowing the expansion of irrigated area to be even more effective in raising overall production levels.

Another supply-side intervention would be that of improving the management of grain storage, so that there are sufficient quantities on hand to provide adequate buffer when there are shocks in either production or supply that cause prices to spike. This has been discussed at length in the recent literature, without a great deal of analysis being applied to it. We will pay a considerable amount of attention to this aspect of policy within the analytical framework that we now present, in the following section.

## 3. QUANTITATIVE OUTLOOK TO 2050

In this section we show some forward-looking outlooks for food production and consumption, that are based on IFPRI's IMPACT model (Rosegrant *et al.*, 2001, 2002, 2005), and also outline the implications that we see for long-term food security. These simulations will help us to show the impact of policy-based and socio-economic drivers on the evolution of agricultural prices – as well as the role that technological interventions and investments can play. These simulations will also help to illustrate the types of entry points that are possible to help stabilize food prices and improve human well-being outcomes, in the face of the various drivers of change that we have discussed, so far.

### 3.1 Description of model

To examine the potential impact of biofuel production growth on country-level and domestic agricultural markets, a partial-equilibrium modeling framework is adopted to capture the interactions between agricultural commodity supply and demand, as well as trade, at global level. The model used is the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT), which was developed by the International Food Policy Research Institute (IFPRI) for projecting global food supply, food demand and food security to year 2020 and beyond (Rosegrant *et al.*, 2001). The IMPACT model is a partial equilibrium agricultural model for crop and livestock commodities, including cereals, soybeans, roots and tubers, meats, milk, eggs, oilseeds, oilcakes/meals, sugar/sweeteners, and fruits and vegetables. It is specified as a set of 115 country and regional sub-models, within each of which supply, demand, and prices for agricultural commodities are determined. The model links the various countries and regions through international trade using a series of linear and nonlinear equations to approximate the underlying production and demand functions. World agricultural commodity prices are determined annually at levels that clear international markets. Growth in crop production in each country is determined by crop and input prices, the rate of productivity growth, investment in irrigation, and water availability. Demand is a function of prices, income, and population growth. IMPACT contains four categories of commodity demand – food, feed, biofuels feedstock, and other uses.

### 3.2 Baseline model projections

#### *Production growth*

The profile of production in cereal over time is shown below in Figure 3, where we see steady trends of output growth to 2050. Cereal production is projected to grow steadily across all seven regions, with North America and Europe leading the regions in cereal production volume. If we look at these trends on a per capita basis, however, we see a somewhat more static picture, in terms of how the various regions are projected to maintain production levels, relative to their populations (Figure 4). In this case, we see that North American, European and Central Asia regions make significant increases in production, relative to their own population growth, and are able to provide the surpluses that are able to supply the food and feed needs of the rest of the world. The

Middle East and North Africa region is able to increase its per capita production levels, as is the Latin America and Caribbean region, over the projections period. By contrast, the South and East Asian regions decrease their per capita production over time, as does sub-Saharan Africa.

### *Demand growth*

In terms of demand growth over the fifty-year period, total food demand for cereals is projected to increase in all regions with North America and Europe, and East Asia leading all other regions in total volume. Table 1 shows how the total demand for cereals is divided into its largest two components (food and feed uses). In terms of food use, the region that shows the strongest demand growth for cereals is sub-Saharan Africa, even though other regions like South Asia, East Asia and the Pacific and Latin America exceeds it in terms of food consumption volume. The Middle East/ North Africa region has similar food demand growth for cereals as South Asia, and those regions with the lowest levels of growth are Eastern Europe and Central Asia, as well as the East Asia and Pacific regions. In terms of feed uses of cereals, the North American and European regions lead the world in total volume of feed consumption, followed by East Asia, Latin America and the Caribbean as well as the Middle East and North Africa aggregate regions.

If we look at the patterns of food demand in per capita terms, then we get a more comparable basis on which to examine the changes in consumption patterns across regions (Figure 5). Looking at the demand for cereals, we see that East and South Asia fall in per capita cereal consumption, compared to the rest of the world. In terms of the demand for meat (Figure 6), which is the main driver of feed demand for cereals, we see that East Asia far outstrips other regions, which is in keeping with its rapid growth in per capita income, compared to other developing and developed regions. Other regions that show large increases in per capita consumption of meat are North America and Europe, which has a far higher level of consumption compared to South Asia and Sub-Saharan Africa, which grow steadily from relatively low levels, due to their steady income growth over this period.

### *Long-term trends in malnutrition*

Given the patterns of supply and demand that have been highlighted, above, the IMPACT model infers a trend in levels of malnourished among the most vulnerable demographic of the population – those aged zero to five. The determinants of malnutrition are derived primarily from four key indicators – per capita calorie availability, access to clean drinking water, rates of secondary schooling among females, and the ratio of female-to-male life expectancy. The link between malnutrition and these determinants were established in the work of Smith and Haddad (2000), who used them as explanatory variables to account for changes in levels of child malnutrition across the developing world, between 1975 and 1995. According to their work, a greater share of the reduction in child malnutrition levels, over this period, can be accounted by improvement in female schooling and clean water access, than in just calorie availability. This finding is in keeping with the four-pillared concept of food security that underlies FAO's conceptual framework – where availability, is only one of the factors that accounts for food security status among vulnerable populations, and must be evaluated along with access, utilization and stability. The methodology used for tracking child malnutrition in IMPACT, therefore, covers aspects of availability, access and utilization – where the concept of access is grounded in the price response of consumption to market conditions, and the utilization aspect is touched upon by access to clean water, which is a major determinant of human health and the ability of the body to absorb and utilize available and accessible nutrients.

The baseline trends for malnutrition are shown in Figures 7 and 8, where we see variation in the rates of change in malnutrition. The decline in malnutrition prevalence, across the various sub-regions of Africa and Asia (Figure 7), shows a steeper decline for the Asian region, compared to sub-Saharan Africa, in the period up to 2025, after which a number of the African sub-regions also show steady declines. The South Asia region has the highest overall levels of prevalence, but is able to make significant reductions by 2050, compared to Southeast Asia and Western sub-Saharan Africa, which are able to decrease the overall levels of prevalence only slightly. East Asia, which already begins with the lowest levels, is able to draw these levels down even further in the longer-term, to achieve single-digit levels of prevalence, which no other region can match. The complete picture of child malnutrition, however, is completed when one looks at the total numbers of malnourished (Figure 8), which shows the Asian region, as a whole, to be the most aggressive in reducing its overall levels of malnutrition, which remain the highest in the world, even in 2050 – compared to sub-Saharan Africa which sees on overall increase in numbers, before the acceleration of production and per capita income levels allow it to reduce its numbers in future. In total numbers, however, the count of malnourished children in Sub-Saharan Africa remains nearly the same in 2050 as compared to year 2000 – even though it represents a smaller share of the overall population. This picture helps to illustrate the challenge that remains in combating hunger and improving human well-being outcomes in the developing world, in the long-term, given the impending pressures that environmental and policy-driven shocks will have on the world food system.

In the following sub-sections, we go into greater detail to discuss the nature of these challenges, and their implications for future food security.

### 3.3 The role of biofuels

#### *An illustrative counterfactual*

Given the complex nature of the various drivers of change that we have described, and the way in which they interact within global agricultural and non-agricultural markets, it is not easy to isolate the effect of biofuels from the other important factors. Nonetheless, in an attempt to do precisely that, we set up a simple counterfactual experiment with the IMPACT model that is designed to show the contrasting impact on cereal prices that the observed historical trends of biofuels growth would exert – if we considered the periods between 1990 and 2000, as well as that between 2000 and 2007, when most of the rapid growth in global biofuels production was realized. In this experiment, we try to see how much global cereal prices would deviate from their observed baseline levels if biofuel production growth were reduced from the actual rates of growth that were observed between 2000 and 2007 and, instead, remained on the trajectory of the previous 1990-2000 period.

As a result of this experimental design, our simulation results produced a rate of growth in average grain prices that is 30% lower than actual rate of increase in world prices over the 2000-2007 period. Following up on this counterfactual experiment, we also carried out a forward-looking set of projections with IMPACT, in which we hold (or 'freeze') the biofuel feedstock demand constant at the observed 2007 levels, rather than continuing along the trend suggested by current policy and plans for future expansion in various key biofuel-producing regions. By carrying out this scenario, we generate results that show grain, oils and cassava prices at least 4% lower than baseline levels in 2015, as well as maize prices that are 14% lower than baseline in 2015. Moreover, as a result of this "freeze" on biofuel growth at 2007 levels, we also see that per-capita levels of calorie availability are 3% higher than baseline levels in 2015, in many developing regions, while regions like Sub-Saharan Africa (where crops like maize are relied upon heavily for staples) would have per-capita levels of calorie availability that are 6% higher than baseline levels in 2015.

#### *Quantifying the implications of renewable fuel targets*

We can also look at specific policies, such as the renewable fuel targets that have been set by various countries, for meeting blending and replacement rates of fossil fuels over a given time horizon. Taking the renewable fuel targets of the United States of America, for example, which sets a target in 2022 for 1st generation biofuel production of 15 billion gallons, under the Energy Independence and Security Act (EISA). The additional amount of maize feedstock that is needed to meet this target is considerable, and requires an additional level of yield growth, shown in figure 9, in order to offset the impacts that it would otherwise have on food security. In other words, the future growth of cereal yields would have to go from an annual average rate of 1.3% to 1.8% in order to equate the implied trends in malnutrition. This translates into an additional 1% of yield growth in the developing world, and an extra 0.5% growth in the developed world – presuming that higher yield gains can be made in less developed countries, where there might still be significant opportunities for closing yield gaps that could be exploited The impact of this offsetting yield increase is shown in Figure 10, where we see the increases in malnutrition in 2025, due to the US policy, being offset by the additional cereal yield growth described above.

These scenarios illustrate the impact of biofuels on global food prices in a fairly clear way, and lead to immediate implications for food security and human well-being. In order to illustrate the way in which specific technological innovations can ameliorate the situation and reduce the pressure that crop-based biofuel production growth poses to global food systems, we carry out some further simulation-based experiments that are described in the next section.

### 3.4 Yield-enhancing technology and policy

An important policy intervention that can be made to alleviate the trade-offs that are embodied in the competing demands for land area to produce the necessary food, feed, fibre and even fuel needs is that of technology – especially in the form of productivity-boosting technologies. Enhancing the yield of food, feed or fibre products per unit area of land, has the effect of not only increasing overall availability of these products (and lowering their market prices, as a result) – but also increasing the availability of land that is available for non-agricultural uses, such as forestry or wildlife habitat, or even for the provision of fuel, in the form of plantation-style biofuel systems. Conversely, increasing the yield of biofuel production systems, through improvements in the productivity and energy yield of the underlying conversion technologies could also have a land-saving effect that increases the area available for growing food and feed products, or other non-agricultural uses.

In some of the global assessments that have been carried out, in the recent past, to assess the future trade-offs between food, feed, and energy needs, and the health of the environment and the ecosystems it supports, some of these very same effects have been noted. In the Millennium Ecosystem Assessment (MA 2005), the scenario that had the highest levels of technology adoption and high income growth (the "Global Orchestration" scenario), also had the highest levels of biofuels production. This arose from the fact that greater investments in increasing agricultural productivity reduced the competition with food-producing land, thereby making more land available for biofuel plantations – and resulting in lower prices for both food and biofuel products. Conversely, the scenario with the lowest levels of income growth and technology adoption – the "Order from Strength" scenario – also had the greatest competition for land under food production (due to lower agricultural productivity and investments), and less biofuels production – resulting in higher food and energy prices. The assessment scenario results also showed that forest land decreased due to the higher levels biofuels – whereas under more extensive agricultural land use patterns, a similar encroachment on forest land would also exist. Both of these results underscore the persistent trade-off s that exist between maintaining ecosystem health and meeting the demands for food, feed, and fuel that exist in all of the scenarios that are considered. Even though there is a difference in the way in which various drivers of change evolve under these scenarios – acting either through increased demand for food, feed, fibre or fuel – there is competition in land uses, and some encroachment upon land that would otherwise remain unmanaged.

The fourth Global Environmental Outlook (GEO-4) of the United Nations Environment Program (UNEP), was a similar global assessment to the MA study, which showed that increased emphasis for meeting targets on greenhouse gas reductions (under either the 'Sustainability First' or 'Policy First' scenarios) could also lead to increased biofuel production and decreases in area under forest (UNEP, 2007). These same scenarios also embodied (in a way that is parallel to the 'Global Orchestration' case in the Millenium Ecosystem Assessment) higher rates of income growth and technology adoption – thereby making agricultural growth more intensive and less extensive in nature, and allowing for more land to be used for non-agricultural uses (including biofuel production). In a similar way, the prices for both food and energy tended to be lower under these high-growth scenarios, due to the higher production of both food and energy products. At the same time, the area of land that is vulnerable to erosion risk also increases, as a result of biofuel production – with the 'Policy First' scenario being the highest one, given that less attention is given to soil conservation and improved land management as under the 'Sustainability First' case.

Given the effects that have been noted the results of the global assessments, we now turn to some biofuel-specific scenarios that will be carried out. In these scenarios, we note both the impact of biofuel production growth on food prices, through demand side effects, as well as the land-saving impact of increased technology growth, which has an effect on the supply side of the agricultural market equation.

As has been done before with IMPACT-based simulations (Rosegrant *et al*., 2001), the "business-as-usual" or 'reference' run describes slowly declining rates of growth in agricultural research (and extension), along the same trend-lines that have been observed in the past. As an alternative to the reference case, we consider a case where levels of agricultural knowledge, science and technology are enhanced – which we call the "high AKST[1]" case. In this variant, we have elevated levels of investments in agriculture over the period 2005-2050. As a result of accelerated investments in agricultural technologies, we have elevated crop yield and livestock numbers growth. A further variant of this considers the implications of even more aggressive growth in agricultural R&D together with advances in other, complementary sectors that provide key infrastructure and social services. Such other sectors include investments in irrigation infrastructure (represented by accelerated growth in irrigated area and efficiency of irrigation water use and by accelerated or reduced growth in access to drinking water, and changes in investments of secondary education for females, an important indicator for human well-being.

### 3.5 Implications for Malnutrition

In the scenarios mentioned above, the increase in crop prices resulting from expanded bio-fuel production is also accompanied by a net decrease in availability and access to food. Calorie consumption is estimated to decrease across regions under the two bio-fuel scenarios compared to baseline levels.

In the case of enhanced AKST levels, we get a significant improvement in food security status and human well-being levels, due to the reduction of price for important tropical staple crops like cassava and maize. In Figure 11, we see that the availability of calories is greatly enhanced, over time, by the acceleration in yield growth and production, realized under higher AKST levels. The effect is particularly strong in SSA, where the improvements in maize and cassava yield have a big impact on calorie availability, given the compositions of diets in that region – and the fact that maize and cassava are important starch foods.

Under higher AKST levels, we see a significant reduction of malnourishment in small children, over time, as a result of the increase in calorie availability in various regions (Figure 12), as well as due to other improvements in socio-economic conditions embedded in the high AKST scenario assumptions. In Figure 12, we see that the level of malnourishment among small children drops strongly, over time, in both sub-Saharan and North Africa, as well as in Latin America. The poorer regions of West Asia and North Africa benefit as much as the tropical regions do, from enhanced access to water, better female schooling rates, and lower food prices – due to the rather poor state of social services in some of those regions. The rates of change are much faster in those regions, even compared to East Asia and the Pacific, or South Asia, and appear to have a stronger progression, even compared to the improvement in calorie availability. This illustrates the importance of other socio-economic factors, besides just food availability, which underlie malnutrition, and how the various 'pillars' of food security – availability, access, utilization and stability –start to interact to produce an effect that might even be greater than the sum of the individual components. While not all of the components of food security can be captured within our modeling framework – those of availability and access (which is closely connected to food prices) are best captured here. Some elements of utilization are captured in the way in which we relate access to clean water to levels of malnutrition, according to the empirical work of Smith and Haddad (2000). In that work, they found that 43% of the decrease in child malnutrition between 1975 and 1995 was due to female schooling, and was the leading determinant – followed by calorie availability (26%).

[1] "AKST" refers to Agricultural Knowledge, Science and Technology – which was a broad concept of agricultural technology and capital that was conceptualized in the recent International Assessment of Agricultural Science and Technology for Development (IAASTD) global assessment. Various scenarios that embody differing levels of AKST were quantified, using a number of models including IMPACT. We have chosen the 'high' case from among those scenario specifications, to use in our illustration.

### 3.6 The added challenge of climate change

In addition to the scenarios that we have presented, that are driven by energy policy, we must also begin to reconcile our accounting of future food balances with the added challenges that climate change will represent to the global food system. It must be said that the ultimate impacts of climate change – both in terms of magnitude and regional specificity – remain somewhat uncertain, as there is a wide spectrum of modeling results that show various degrees of impact for the same regions of the world. A great part of this uncertainty in the results of the Global Circulation Models (GCMs) lies in the fact that each of them models the interactions between the atmosphere, the ocean and terrestrial systems differently, which results in greater divergences in model results as one moves out in time. For this reason, the Inter-governmental Panel on Climate Change (IPCC) tried to portray the wide variance in model results in both its 3rd and 4th assessment reports, and we have chosen to take the more "extreme" of those examples, to include in our model results.

We must also report, at this juncture, that the methodology that we have used to account for climate change "shocks" within our modeling framework, is still under revision and is subject to change in the near future. The main challenge lies in the reconciliation of biophysical modeling results – which are run at a relatively micro-level scale of resolution – with the workings of an aggregate-level, market equilibrium-driven policy model, such as IMPACT, which has to take the average of crop level effects across space. The marriage of these two elements – the biophysical process-driven elements, and economic equilibrium-driven mechanisms – is complex, and is a subject of continuing research. We have also not fully attributed the possible effects that carbon fertilization could have on future crop yields, due to the uncertainty that still exists in trying to quantify this result for various agronomic zones, where on-the-ground reality could differ significantly from carbon fertilization experiments in the laboratory.

Notwithstanding these difficulties, we have elected to present some preliminary results that show the overall magnitude of climate change impacts on global agricultural markets, so that we can begin to discuss the implications of this, in terms of both national and household-level economic effects. For our illustration, we have taken the more extreme "A2a" climate scenario, which represents that socio-economic scenario in which there is higher emphasis on fossil-based fuels, and less cooperation and (clean) technology-sharing across the globe. This type of outcome is similar to the less favorable scenarios of both the Millenium Ecosystem assessment, as well as the UNEP GEO-4 assessment, in terms of portraying a less harmonious, cooperative and purely growth-driven kind of world geopolitical atmosphere.

Figures 13, 14 and 15 show the projected impact of climate change on global prices, for three major cereal commodities that are of key importance to both food and feed uses. The more than doubling of the global market price for maize in 2050 due to climate change (Figure 13), implies strong effects for the livestock industry, which rely on maize for food, as well as for those food consumers of maize, in Sub-Saharan Africa. The less dramatic, but equally important increases in rice and wheat prices have a stronger implication for food uses than for feed uses, and would likely be propagated widely throughout the world food system. Granted that these increases do not necessarily represent sudden spikes in price that occur in 2050, but a gradual accumulation of price pressures that build over time in response to the steady and constant tightening of supplies, as the suitability for crop growth is reduced in various key cereal-growing regions of the world. Nonetheless, these differences do demonstrate that the added pressure on global food supplies would be significantly increased if the environmental drivers embedded in these climate change scenarios were to be realized, and that responsive policy action and adaptation would have to occur, in order to offset these effects. These adapative actions are not, actually, embedded in our results, as the endogenous technology choices of agents is not fully represented in our model. These types of adaptations and technology choices would have to be introduced by scenario, in order to account for the possibility of improved seed variety and other adaptive on-farm improvements, which are not endogenous within our framework. We plan to do these types of adaptation-focused scenarios in further work.

We also show the implications for these climate-driven changes in world food prices, in terms of the effect on child malnutrition outcomes. Looking at the Asian region (Figure 16), we see that the overall progress towards the reduction of malnourishment levels is not greatly hindered in the Asian region, because of these climate pressures, but that there is still an appreciable difference between the 2050 outcomes that are with and without climate change. Given that calorie availability is only one component of the food security measure that we use, this illustrates the fact that it is important to keep the other important socio-economic components of household food security on track, if we are to avoid being seriously derailed, in future, by the additional stress that global climate change poses to our collective food futures.

## 4. IMPLICATIONS FOR FOOD SECURITY AND POLICY

Now we will discuss the implications suggested by the scenario results that we have seen in the previous section, in light of the current global food situation. In particular we would like to discuss the implications for household-level welfare.

### 4.1 Micro-level impacts and household welfare

Price changes in food and energy markets influence households directly through market prices or indirectly via cost of production or transportation for other marketed goods. Net sellers and net buyers are affected differently, and even though net sellers gain from price increases, there gains may not be enough to offset the negative impacts that net buyers undergo. From FAO data, we see that in some of the poorest countries, a relatively small share of households are net sellers of the staple foods that are experiencing the strongest price effects. A country like Bangladesh would only have slightly under 16% of all households as net sellers of staples, according to year 2000 data, compared to a country like Vietnam which showed a share slightly over 40% in 1998 (FAO, 2008). Developing countries like Madagascar, which had almost 51% of their households in 1993 as net sellers, would be unusual, compared to countries like Guatemala and Malawi which had slightly over 10% and almost 12% in 2000 and 2004, respectively.

The recent working paper of Ivanic and Martin (2008), showed that the impacts of high food prices had a differential effect on poverty rates and incidence, depending upon this very question of net seller and buyer position of various households. In their analysis, a country like Vietnam could (and probably did ) experience a net reduction in poverty rates, due the fact that increased rice prices put those rural households who were net sellers into a much better position than before. Likewise, Peru might also get poverty reductions, due to the fact that increased maize prices would favor those rural households who were in a net seller position. The benefits in Madagascar would arise from maize and dairy, whereas those in Pakistan arise from rice, dairy and wheat. So the impacts vary according to region and commodity, and depend upon the particular structure of the national economy, and the agricultural economy, in particular. Most of the positive benefits that Ivanic and Martin document are in rural areas, whereas urban households tend to bear the negative impacts of higher prices, across the board. In their study they did account for the wage effects, which will be more pronounced (and positive) for the rural households who sell their labor to the agricultural sector.

The means by which households adjust their production and consumption, in response to economic shocks is shown in Figure 17, which illustrates the various dimensions of response that can be undertaken to adjust. Given that a number of expenses might be quasi-fixed, such as rent (especially for urban-dwellers), a good deal of adjustment must come from the food consumption side, often leading to poorer diets and lower levels of essential nutrient intake. For those households with other assets, they can dis-invest to the extent that is possible, in order to smooth consumption in the short-term. Often, however, these dis-investments do not get reversed in future periods, when economic conditions ease, resulting in reduced endowments and enhanced vulnerability to future shocks. The tendency to pull children – especially girls (Schultz, 2002) – from school in times of hardship leads to longer-term effects that arise from decreased investments in human capital and reduced earning capacity and productivity in future.

Some might argue that biofuels, despite causing increases in food prices, could lower the costs of energy to households, and generate some benefits that might not otherwise be accounted for. The specific outcome depends on the shares of household income that go towards food and energy purchases and these shares vary by income level. From the data that we can observe on household level expenditure patterns, we see that those household which lie at the poverty line tend to spend upwards of 50% of their household income on food – whereas that spent on energy is much smaller (Ahmed *et al.,*2007).

### 4.2 Policy implications

From the evidence and experimental results that we have presented, a number of policy recommendations come to the fore, as being especially pertinent to addressing the world food situation, and its implications for current and future levels of human welfare. Some are of a technological nature, while other pertain more to policy-level interventions, which are both at the national- and global-level.

In terms of specific technological interventions that can address the decline in productivity of key staple crops that have been observed, there are a wide range of improved crop varieties that can be adopted in regions that have relied mostly on traditional but lower-yielding varieties. Some of this varietal improvement will be necessary, just to maintain yields at current levels, in the face of increasingly adverse environmental conditions – such as those brought on by elevated temperature levels, decreased rainfall or increased incidence of crop pests and diseases (which often move over space as a result of changes in the aforementioned temperature and rainfall conditions). A key agricultural technology that was instrumental in allowing the south Asian green revolution to take off was that of irrigation, which is drastically under-invested in certain regions of the world, like sub-Saharan Africa. These increases in irrigation, however, would have to be accompanied by corresponding investments in installing adequate drainage facilities, so that problems of salinity are avoided. In those regions with existing (and increasing) levels of soil salinity, improvement of drainage might also have to be accompanied by adoption of more salt-tolerant crop varieties, in order to maintain yields at the needed levels of for future supply growth.

Some of the obvious policy interventions that are related to the use of agricultural feedstocks for 'first-generation', conventional biofuel production, are those of limiting or perhaps even avoiding the use of food crops in the production of biofuels like ethanol and biodiesel. There are a variety of policy instruments that support biofuels production, such as direct support to biofuel producers and blenders, as well as national blending targets or mandates – as well as trade instruments, which might raise the barriers to imported biofuels from other regions (or encourage their export from others). Technology adoption will largely remain a private industry-driven dynamic, but can be helped from a policy level by increased spending on research and development that is aimed at pushing forward the next generation of conversion technologies and feedstocks. While there are a number of trade-related policy instruments need to be addressed at the country-level, there is also a need for policy (and political) coordination at the global level, in order to effect multi-lateral agreements that can lead toward the liberalization of international trade. As far as biofuels are concerned, trade policy has a large influence on trade and prices through biofuel feedstock and more importantly, trade of biofuels themselves. In practice, allowing for freer trade in ethanol means that gasoline can more easily be replaced by renewable fuels whenever energy prices rise. In addition, if designed poorly, tariffs, tax credits, subsidies and mandates can lead to perverse effects – such as the possibility of actually increasing fossil fuel consumption, as noted by De Gorter and Just (2007).

In terms of social protection of the most vulnerable sections of the population, there is a lot that can be accomplished through policy-driven strengthening of national social 'safety net' programs, that allow for relief for those who are most threatened by escalating food prices, while avoiding 'blanket' policies like price controls, which are easier (and cheaper) for governments to enact – but which have the perverse effect of reducing the producer response that could otherwise soften the price rises through increased output. The main challenge of policy, in this case, is to maintain a balance between maintaining producer incentives, and not introducing distortions that might counteractively dampen the self-correcting responses that are needed, while still supporting human welfare through protecting the most vulnerable. The careful targeting of interventions to those most in need requires deliberate and careful policy design, which is often lacking in indiscriminate food subsidy-type schemes, which might still benefit a lot of the poor (especially if they're the majority consumers of the targeted staples), but might also benefit the better-off households who have other degrees of adjustment (or assets) to exploit.

## 5. CONCLUSIONS

In this paper, we have explored the nature of several key drivers of change in food systems, and examine a number possible entry points for policy intervention, in order to determine their effect on food prices and other market-driven outcomes. Among the drivers of change that we discuss are those of policy-driven growth in biofuel production, which has had a role to play in the rapid increase in food prices, along with other factors such as global climate change. We demonstrated the off-setting impact that supply growth could have on the socio-economic impacts of biofuels, both in terms of price changes, as well as changes in nutrition status. We also make the argument that it is important to be cognizant of all the components of food security – and not just focus on the one of food production and output – in order to maintain progress towards reducing levels of malnutrition and improving human well-being.

Based on the discussion above, this paper argues that certain policy responses should be avoided in dealing with high prices. These include export bans (akin to a 'starve-your-neighbor' policy), import subsidies, restoration of production subsidies, subsidies for the vocal middle class, policing and threatening traders and attempting to curb food price inflation with macroeconomic policies. On the other hand, the following three broad policy areas would represent desirable and effective tools in fighting the challenges and negative side-effects posed by high food prices: trade, agricultural growth and protection of the vulnerable.

The pressures of high food prices can be alleviated by eliminating trade barriers and export bans and by better enabling international institutions to raise the financing and mobilize the resources needed to effect emergency food imports for the neediest countries. Agricultural growth can be revitalized by expanding aid for rural infrastructure, services, agricultural research and technology. Finally, the vulnerable can be shielded from the worst effects of high food prices by expanding food and nutrition related aid, including safety nets, child nutrition and employment programs.

In summary, a two track approach is needed in developing countries. It should include a global and national food, health, and nutrition security initiative focused on the vulnerable as well as an agricultural productivity initiative focused on small farmers.

Combining our quantitative experiments with cited evidence from other studies, we suggest a range of policy interventions that could be instrumental in offsetting the negative impacts of food prices, and helping to promote those benefits in situations where they might exist – in order to encourage increased investments in the agricultural sector, and reverse the steadily declining trend of research and development spending and decades of counter-productive agricultural trade and national-level sector policy.

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## APPENDIX: FIGURES & TABLES

**Figure 1: The interrelationships between key drivers of change in food systems and their connection to human well-being**

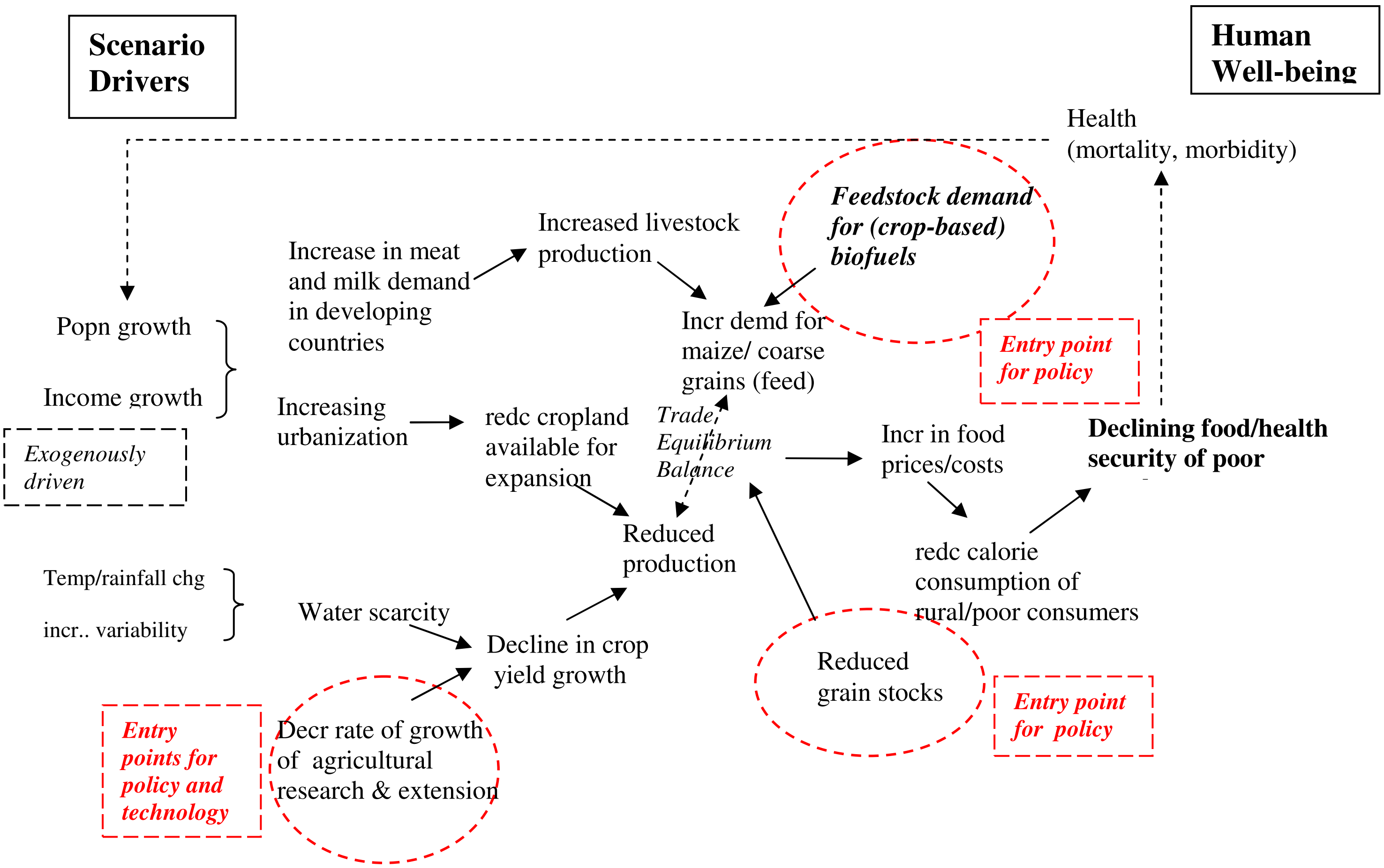


**Figure 2: Characteristics of various drivers of change in food systems**

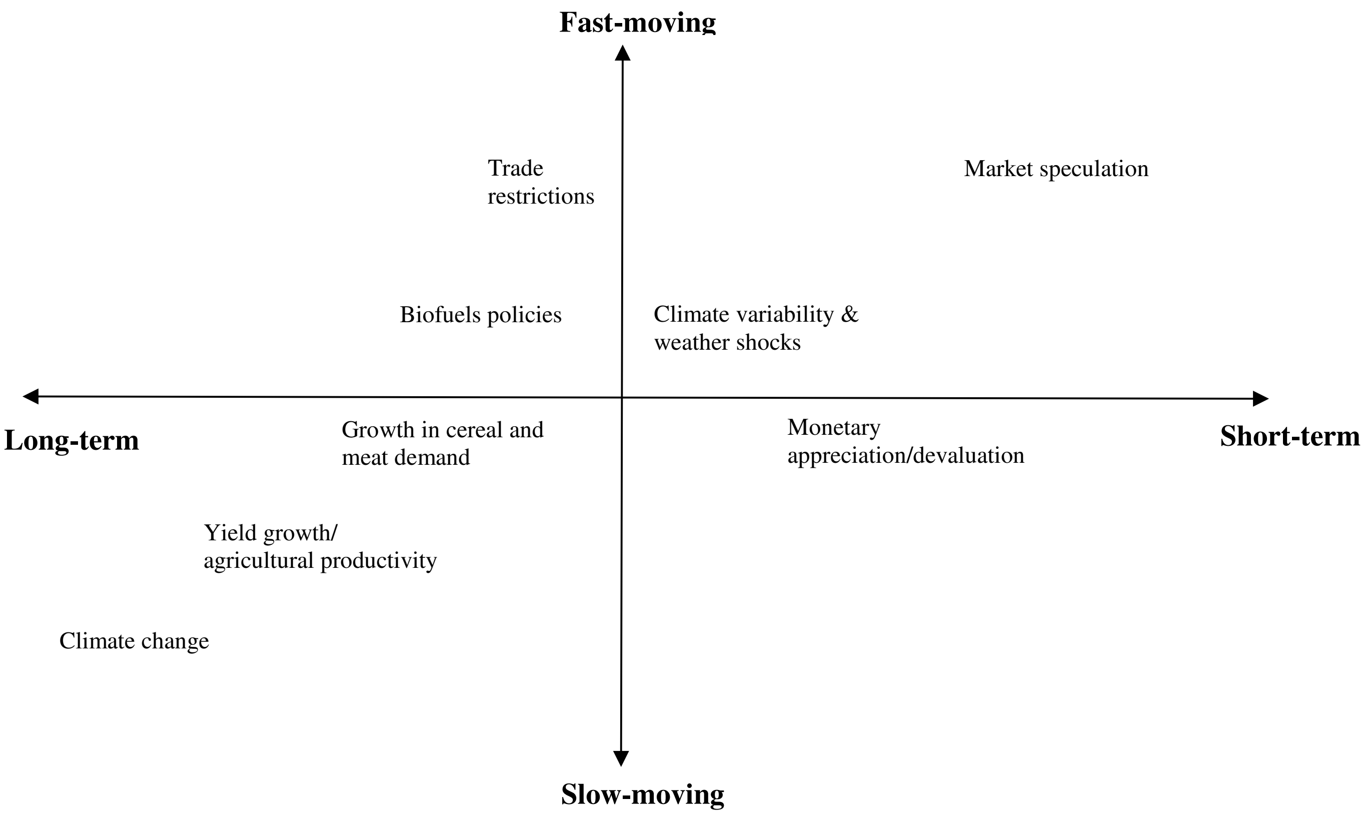
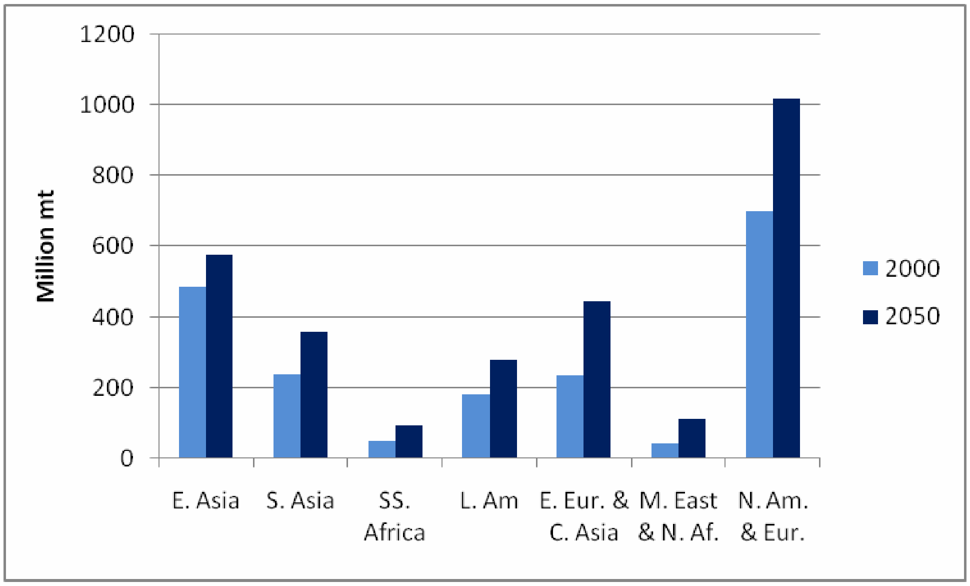


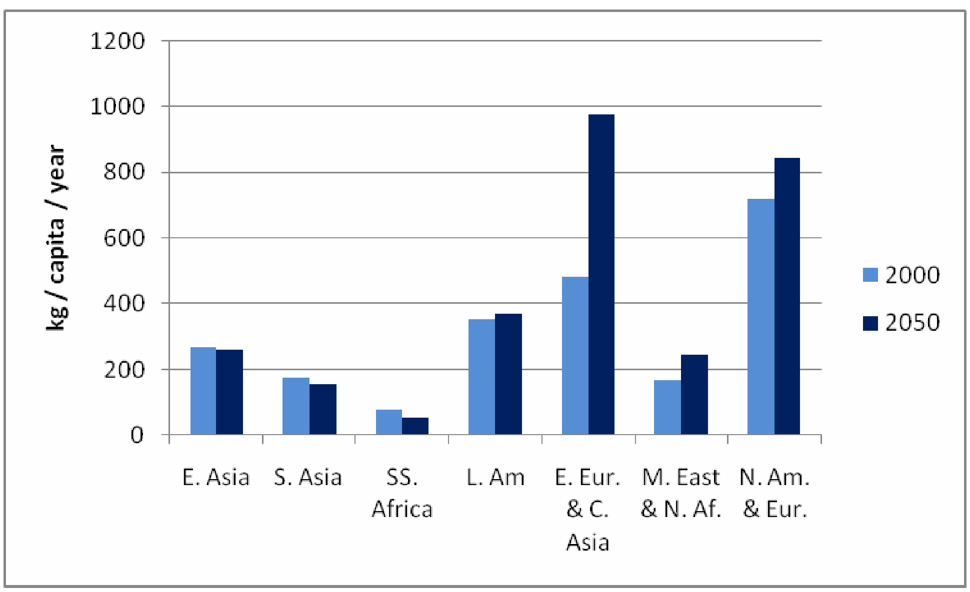
**Figure 3: Total Cereal Production to 2050 (millions of metric tons)**




Source: IFPRI IMPACT projections.

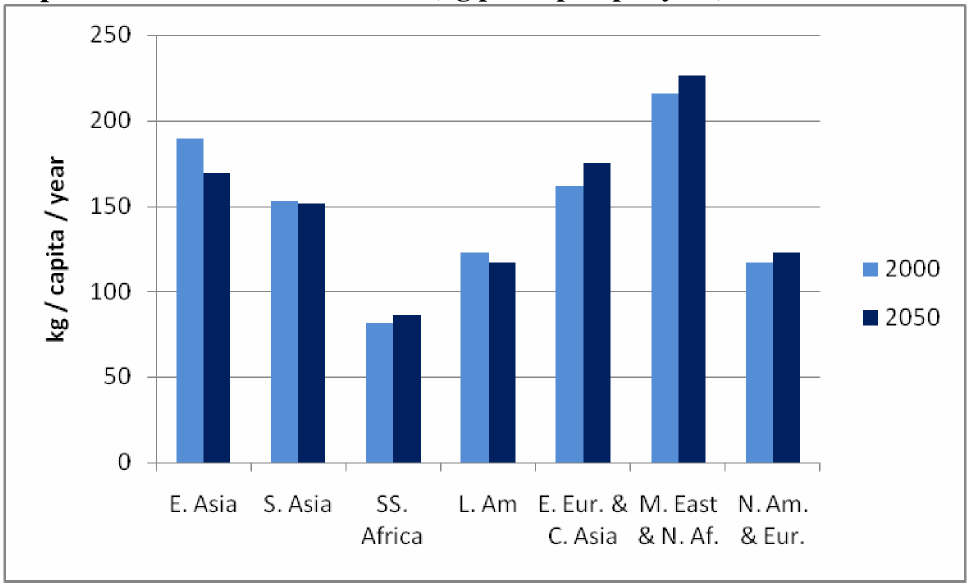
Note: Nrt Am & Eur = North America and Europe, SS Africa = Sub-Saharan Africa, S Asia = South Asia, C&W Asia N Af = Central and West Asia & North Africa, L Am & C = Latin America & the Caribbean, SE Asia & P = SouthEast Asia & Pacific.

**Figure 4: Per Capita Cereal Production to 2050 (kg per capita per year)**




Source: IFPRI IMPACT projections.
Note: Nrt Am & Eur = North America and Europe, SS Africa = Sub-Saharan Africa, S Asia = South Asia, C&W Asia N Af = Central and West Asia & North Africa, L Am & C = Latin America & the Caribbean, SE Asia & P = SouthEast Asia & Pacific.

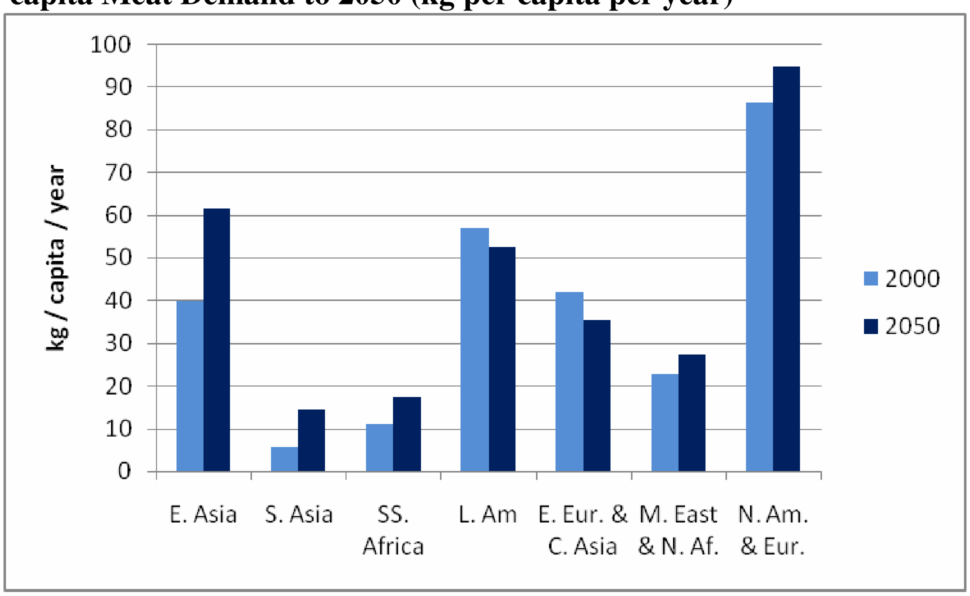
**Figure 5: Per capita Cereal Demand to 2050 (kg per capita per year)**




Source: IFPRI IMPACT projections.

Note: Nrt Am & Eur = North America and Europe, SS Africa = Sub-Saharan Africa, S Asia = South Asia, C&W Asia N Af = Central and West Asia & North Africa, L Am & C = Latin America & the Caribbean, SE Asia & P = SouthEast Asia & Pacific.

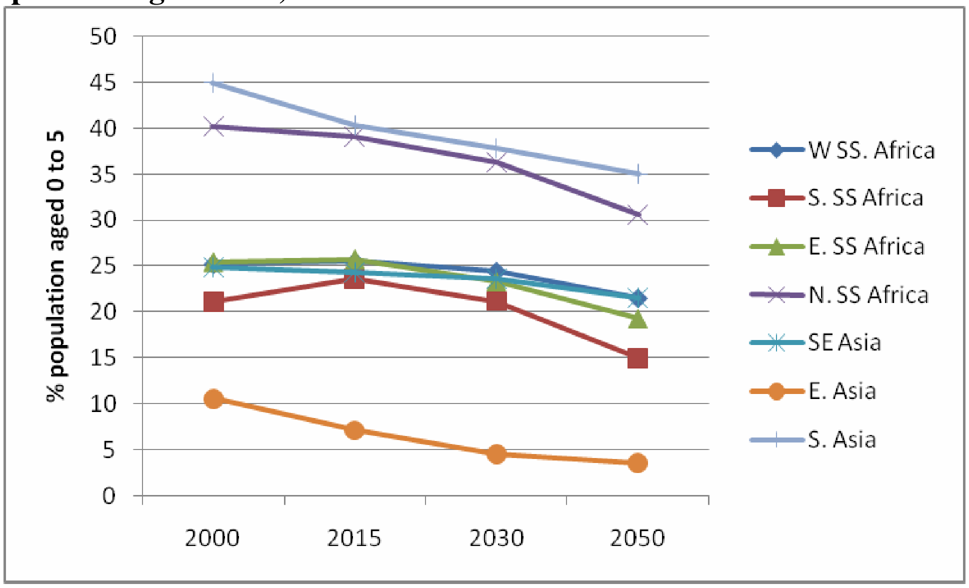
**Figure 6: Per capita Meat Demand to 2050 (kg per capita per year)**




Source: IFPRI IMPACT projections.

Note: Nrt Am & Eur = North America and Europe, SS Africa = Sub-Saharan Africa, S Asia = South Asia, C&W Asia N Af = Central and West Asia & North Africa, L Am & C = Latin America & the Caribbean, SE Asia & P = SouthEast Asia & Pacific.

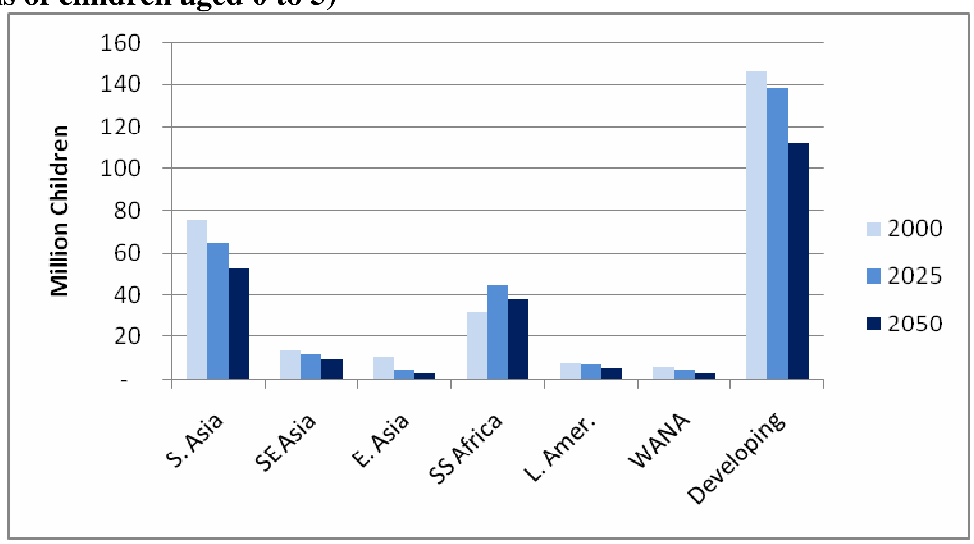
**Figure 7: Prevalence of pre-School Child Malnutrition in Asia and Africa (% of population aged 0 to 5)**




Source: IFPRI IMPACT projections.

Note: N/S/E/W. SS Africa =Northern/Southern/Eastern/Western Sub-Saharan Africa, S Asia = South Asia, E Asia = East Asia, SE Asia = SouthEast Asia.

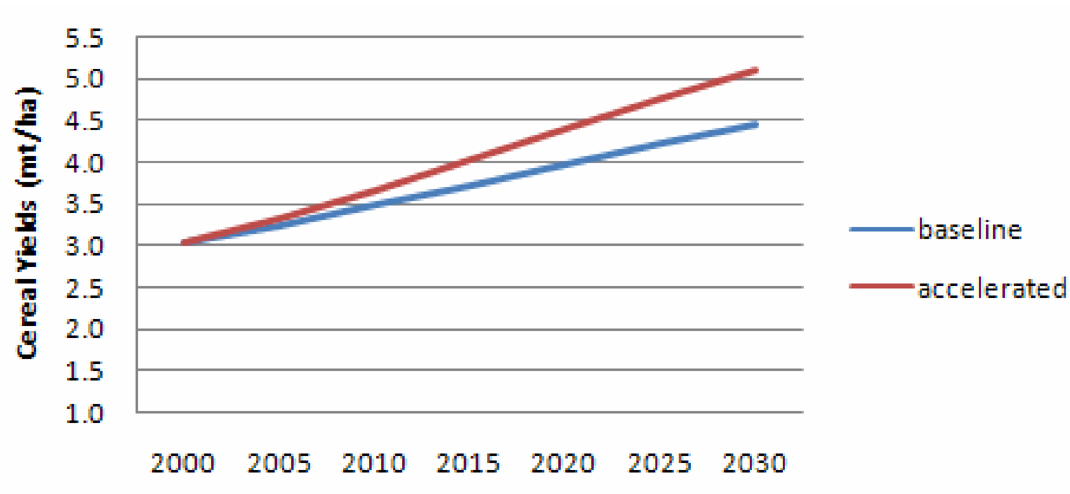
**Figure 8: Total Levels of pre-School Child Malnutrition in Developing World (millions of children aged 0 to 5)**




Source: IFPRI IMPACT projections.

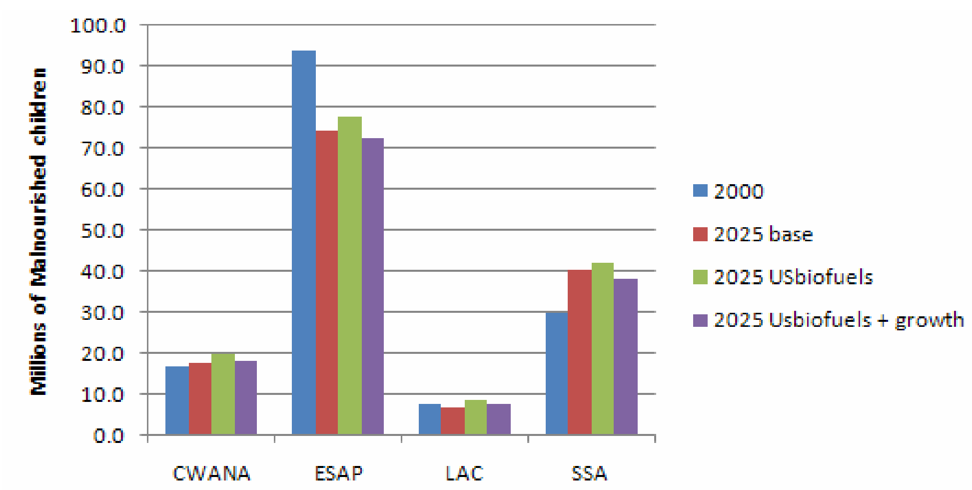
Note: SS Africa = Sub-Saharan Africa, W Asia & N Africa = West Asia & North Africa, L Am & C = Latin America & the Caribbean.

**Figure 9: Additional global cereal growth needed to offset impacts of US biofuels target**




Source: IMPACT model simulations

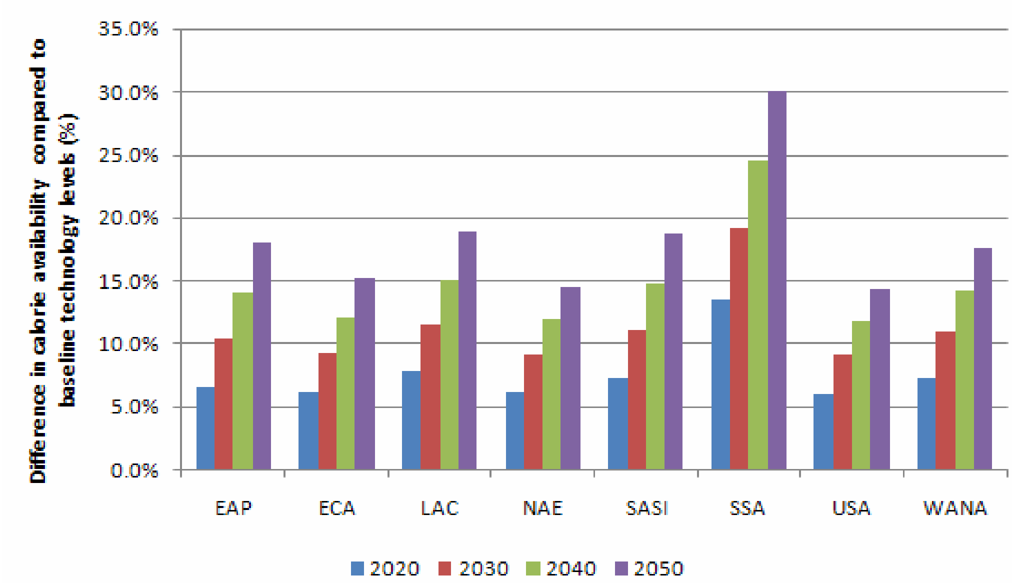
**Figure 10: Trends in child malnutrition to 2025 under the baseline case**




Source: IFPRI IMPACT projections.

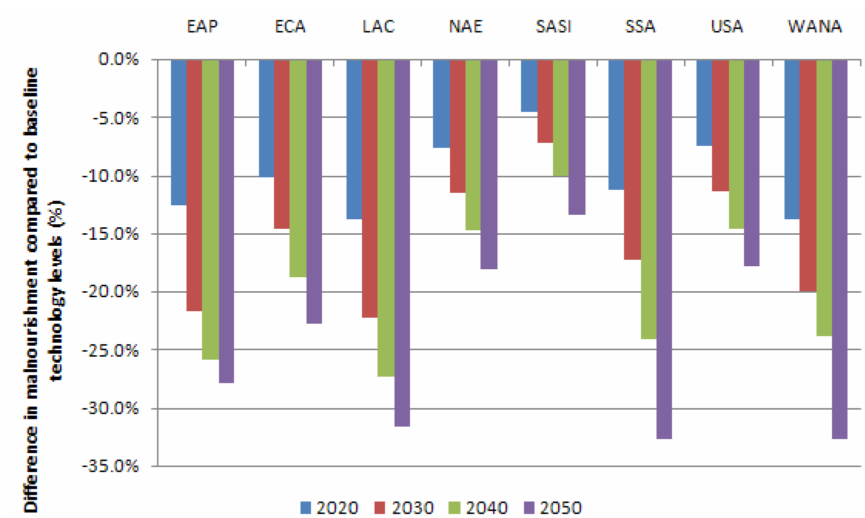
Note: CWANA = Central & West Asia & North Africa, EASP = East Asia & Pacific, LAC = Latin America and Caribbean SSA = Sub-Saharan Africa.

**Figure 11: Calorie availability increases compared to biofuel expansion under baseline technology levels (% difference from baseline technology case)**




Source: IFPRI IMPACT projections.
Note: N America = North America, SSA = Sub-Saharan Africa, S Asia = South Asia, MENA = Middle East & North Africa, LAC = Latin America & the Caribbean, ECA = Europe & Central Asia, EAP = East Asia & Pacific.

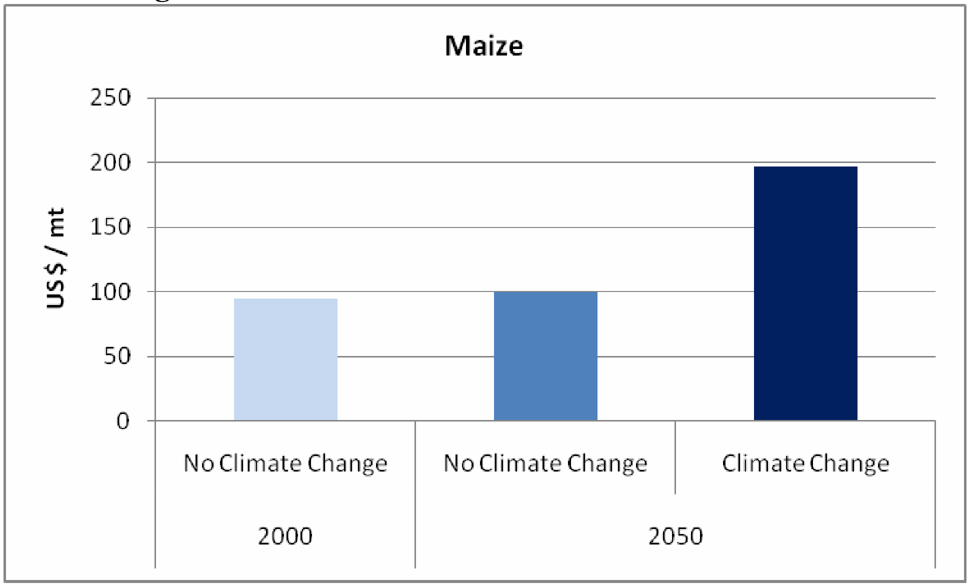
**Figure 12: Decreases in numbers of malnourished children compared to biofuel expansion under baseline technology levels (thousands of children)**




Source: IFPRI IMPACT projections.

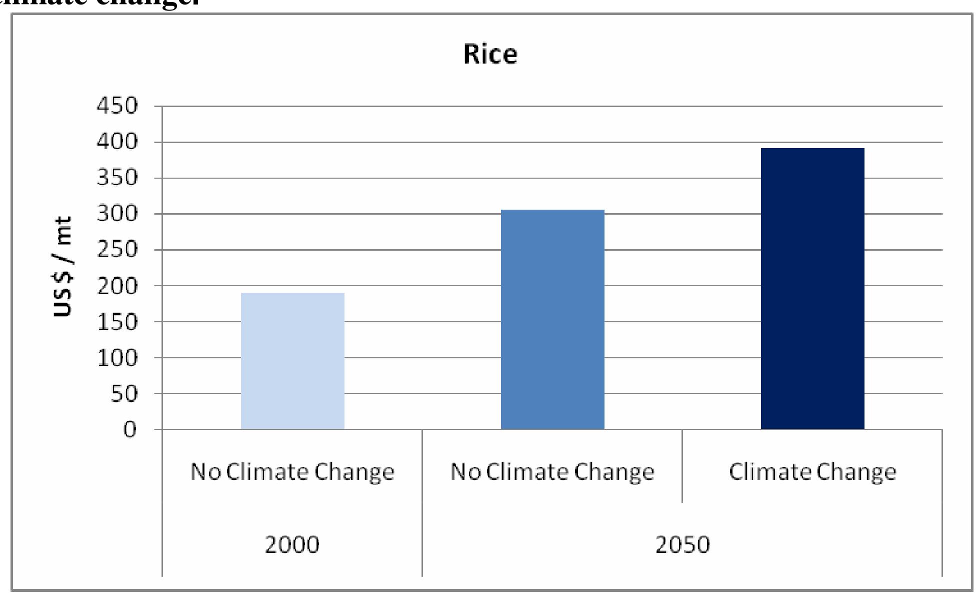
Note: N America = North America, SSA = Sub-Saharan Africa, S Asia = South Asia, MENA = Middle East & North Africa, LAC = Latin America & the Caribbean, ECA = Europe & Central Asia, EAP = East Asia & Pacific.

**Figure 13: Global commodity-level maize prices in year 2000 and 2050 under scenarios with and without climate change.**



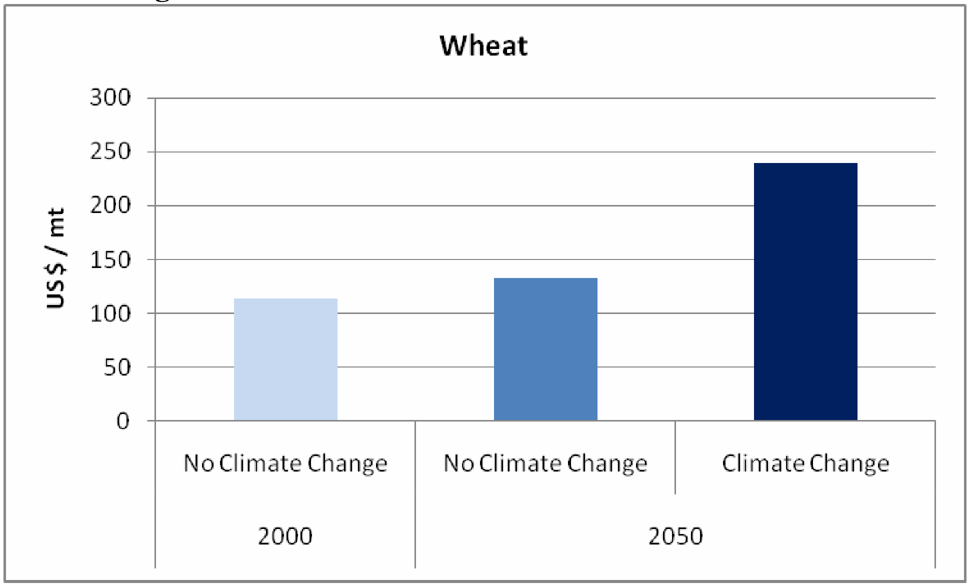

Source: IMPACT model simulations

**Figure 14: Global commodity-level rice prices in year 2000 and 2050 under scenarios with and without climate change.**



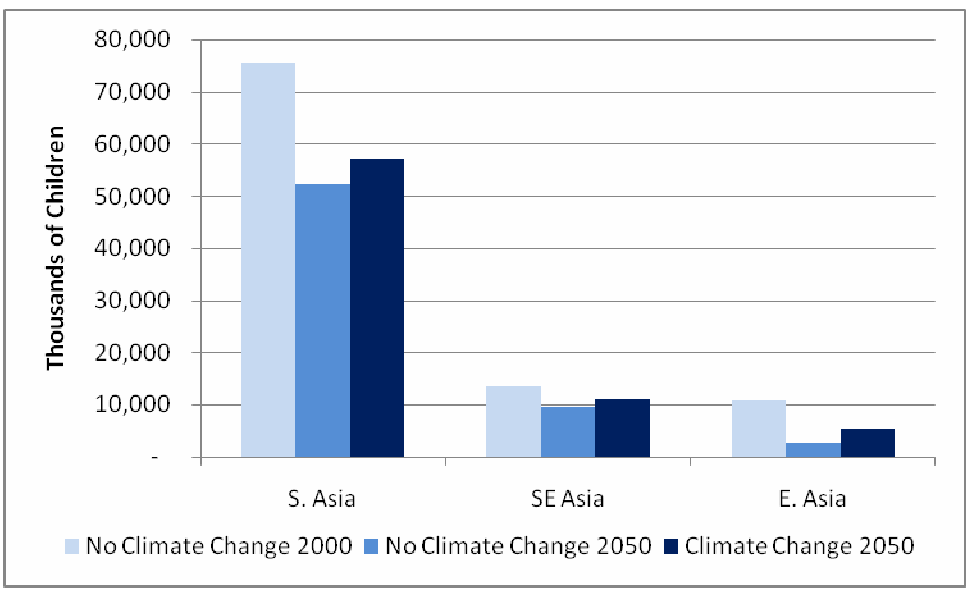

Source: IMPACT model simulations

**Figure 15: Global commodity-level wheat prices in year 2000 and 2050 under scenarios with and without climate change.**




Source: IMPACT model simulations

**Figure 16: Total number of malnourished Children in developing Asia (thousands of children, under 5 yrs of age)**




Source: IMPACT model simulations

**Figure 17: Schematic of Household Income and Expenditure Adjustments**

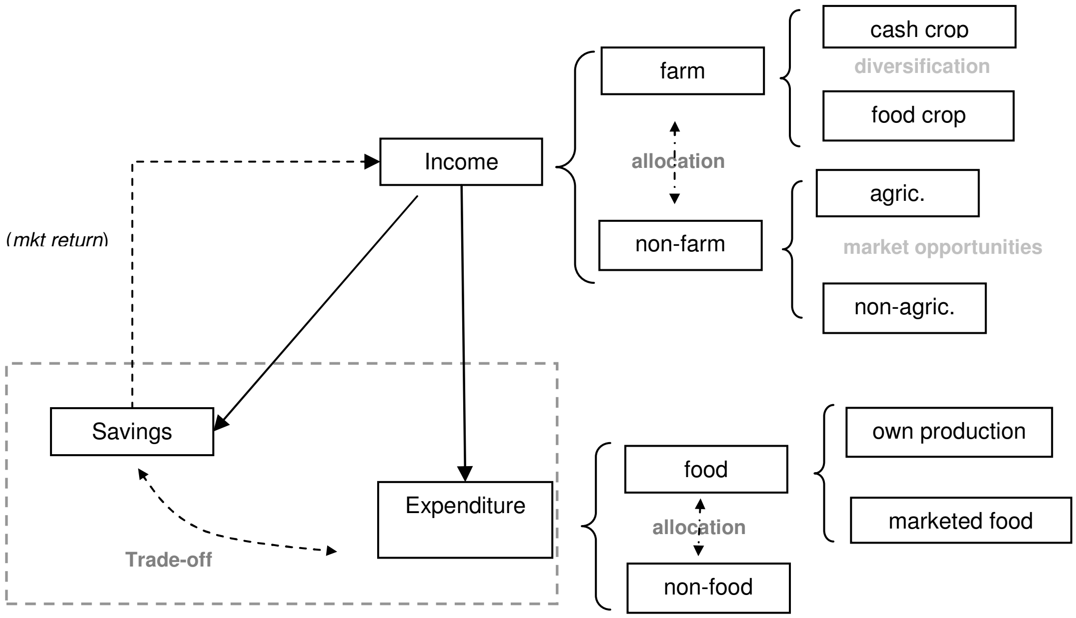



**Table 1. Total, Feed and Food Demand for Cereals (millions of metric tons)**

| | Total | | | Food | | | Feed | | |
|---|---|---|---|---|---|---|---|---|---|
| | **2000** | **2050** | **% chg** | **2000** | **2050** | **% chg** | **2000** | **2050** | **% chg** |
| South Asia | 250 | 427 | 71% | 218 | 360 | 66% | 3 | 12 | 266% |
| East Asia and Pacific | 524 | 688 | 31% | 347 | 376 | 8% | 102 | 205 | 100% |
| Europe and Central Asia | 235 | 267 | 13% | 79 | 80 | 1% | 108 | 124 | 14% |
| Latin America and Caribbean | 180 | 287 | 60% | 63 | 88 | 40% | 50 | 112 | 122% |
| Middle East and North Africa | 90 | 182 | 103% | 56 | 102 | 83% | 23 | 58 | 147% |
| Sub-Saharan Africa | 84 | 243 | 190% | 65 | 187 | 189% | 7 | 18 | 155% |
| North America and Europe | 619 | 853 | 38% | 114 | 148 | 30% | 324 | 401 | 24% |

Source: IFPRI IMPACT projections.

Note: N America = North America, SSA = Sub-Saharan Africa, S Asia = South Asia, MENA = Middle East & North Africa, LAC = Latin America & the Caribbean, ECA = Europe & Central Asia, EAP = East Asia & Pacific.

# THE RESOURCE OUTLOOK TO 2050:[1]

## BY HOW MUCH DO LAND, WATER AND CROP YIELDS NEED TO INCREASE BY 2050?

**Jelle Bruinsma**[2]

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[1] Paper presented at the FAO Expert Meeting, 24-26 June 2009, Rome on "How to Feed the World in 2050".

[2] Consultant with the Global Perspective Studies Unit at FAO. Substantial contributions by Gerold Boedeker, Jean-Marc Faures, Karen Frenken and Jippe Hoogeveen as well as comments on an earlier draft by FAO staff are gratefully acknowledged. The author alone is responsible for any remaining errors. The views expressed in this information product are those of the author(s) and do not necessarily reflect the views of the Food and Agriculture Organization of the United Nations.

## SUMMARY AND CONCLUSIONS

This paper discusses the natural resource implications of the latest FAO food and agriculture baseline projections to 2050 (FAO, 2006a). These projections offer a comprehensive (food and feed demand, including all foreseeable diet changes, trade and production) and consistent picture of the food and agricultural situation in 2030 and 2050. The main purpose of this paper is to provide an indication of the additional demands on natural resources derived from the crop production levels in 2030 and 2050 as foreseen in the FAO 2006 projections. It does not deal with additional demand for agricultural products used as feedstock in biofuel production or the impacts of climate change (these are dealt with in another paper, G. Fischer 2009, for this expert meeting), nor the additional production needed to eliminate (or to accelerate the elimination of) the remaining undernourishment in 2050.

Growth in agricultural production will continue to slow down as a consequence of the slowdown in population growth and of the fact that an ever increasing share of world population is reaching medium to high levels of food consumption. Nevertheless, agricultural production would still need to increase by 70 percent (nearly 100 percent in developing countries) by 2050 to cope with a 40 percent increase in world population and to raise average food consumption to 3130 kcal per person per day by 2050. This translates into an additional billion tonnes of cereals and 200 million tonnes of meat to be produced annually by 2050 (as compared with production in 2005/07).

Ninety percent (80 percent in developing countries) of the growth in crop production would be a result of higher yields and increased cropping intensity, with the remainder coming from land expansion. Arable land would expand by some 70 million ha (or less then 5 percent), the expansion of land in developing countries by about 120 million ha (or 12 percent) being offset by a decline of some 50 million ha (or 8 percent) in the developed countries. Almost all of the land expansion in developing countries would take place in sub-Saharan Africa and Latin America.

Land equipped for irrigation would expand by some 32 million ha (11 percent) while the harvested irrigated land would expand by 17 percent. All of this increase would be in the developing countries. Mainly (but not only) due to slowly improving water use efficiency, water withdrawals for irrigation would grow at a slower pace but still increase by almost 11 percent (or some 286 cubic km) by 2050.

Crop yields would continue to grow but at a slower rate than in the past. This process of decelerating growth has already been underway for some time. On average, annual growth over the projection period would be about half (0.8 percent) of its historical growth rate (1.7 percent; 0.9 and 2.1 percent for the developing countries). Cereal yield growth would slowdown to 0.7 percent per annum (0.8 percent in developing countries), and average cereal yield would by 2050 reach some 4.3 tonne/ha, up from 3.2 tonne/ha at present.

Are the projected increases in land, water use and yields feasible? The Global Agro-Ecological Zone study shows that there are still ample land resources with some potential for crop production left, but this result needs to be heavily qualified. Much of the suitable land not yet in use is concentrated in a few countries in Latin America and sub-Saharan Africa, i.e. not necessarily where it is most needed, and much of the potential land is suitable for growing only a few crops not necessarily the crops for which there is the highest demand. Also much of the land not yet in use suffers from constraints (chemical, physical, endemic diseases, lack of infrastructure, etc.) which cannot easily be overcome (or it is economically not viable to do so). Part of the land is under forests, protected or under urban settlements, and so on. Overall however it is fair to say that, although there are a number of countries (in particular in the Near East/North Africa and South Asia) that have reached or are about to reach the limits of land available, on a global scale there are still sufficient land resources left to feed the world population for the foreseeable future.

The availability of fresh water resources shows a very similar picture as land availability, i.e. globally more than sufficient but very unevenly distributed with an increasing number of countries or regions within countries reaching alarming levels of water scarcity. This is often the case in the same countries in the Near East/North Africa and South Asia that have no land resources left. A mitigating factor could be that there are still ample opportunities to increase the water use efficiency (e.g. through providing the right incentives to use less water).

The potential to raise crop yields (even with existing technology) seems considerable. Provided the appropriate socio-economic incentives are in place, there are still ample 'bridgeable' gaps in yield (i.e. the

difference between agro-ecologically attainable and actual yields) that could be exploited. Fears that yields (e.g. for rice) are reaching a plateau do not seem warranted (except in a few very special instances).

Towards the end of the projection period there are signs of an increasing number of countries (and not only what at present are termed 'developed countries') reaching 'saturation' levels, i.e. agricultural production hardly grows anymore and arable land is taken out of production. Likewise, although land allocated to crops such as maize and soybeans would still increase considerably, land allocated to crops such as rice, potatoes and pulses would decline. Naturally, apart from rising yields, this reflects slowing (or even declining) population growth, medium to high food consumption levels and the shift in diets to livestock products with more land allocated to crops used for feeding purposes.

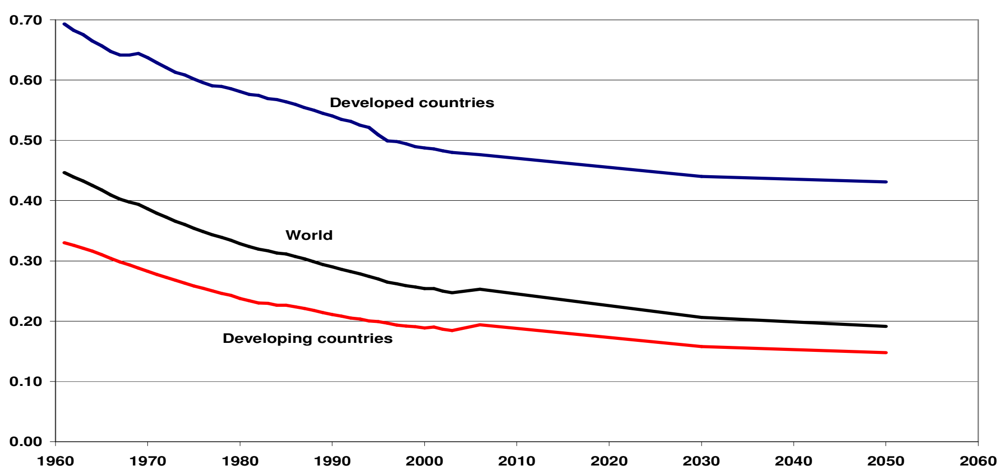
Does this mean that all is well? Certainly not. The conclusion that the world as a whole produces or could produce enough food for all is small consolation to the persons and countries (or regions within countries) that continue to suffer from undernourishment. The projected increases in yields, land and irrigation expansion will not entirely come about spontaneously (i.e. driven by market forces) but require huge public interventions and investments, particularly in agricultural research and in preventing and mitigating environmental damage. In the problem countries, public intervention will continue to be required on the one hand to develop agriculture and to adapt agriculture to local circumstances and on the other hand to establish social safety nets.

## INTRODUCTION

The recent food crisis, characterized by sharp food price surges and in part caused by new demands on agriculture such as demand for biomass as feedstock in biofuel production (see Alexandratos, 2008), made fears that the world is running out of natural resources (foremost among them land and fresh water resources) come back with a vengeance (see for example Brown, 2009). Concerns are voiced that agriculture might in the not too distant future no longer be able to produce the food needed to feed a still growing world population at levels sufficient to lead a healthy and active life.

Such fears are by no means new and keep continually coming back prompting a series of studies and statements concerning the question how many people the earth can support. The continuing decline of arable land per person (Figure 1) is often cited as an indicator of impending problems[3]. The underlying cause for such problems is perceived to be an ever increasing demand for agricultural products facing finite natural resources such as land, water and genetic potential. Scarcity of these resources would be compounded by competing demands for them originating in urbanization, industrial uses and use in biofuel production, by forces that would change their availability such as climate change and the need to preserve resources for future generations (environmentally responsible and sustainable use).

**Figure 1: Arable land per caput (ha in use per person)**




[3] Of course, one could interpret declining land per person combined with increasing average food consumption as a sign of ever increasing agricultural productivity.

This paper will address a few of the above-mentioned issues by unfolding the resource use implications of the crop production projections underlying the latest FAO perspective study (FAO, 2006a, "World agriculture: towards 2030/2050 – Interim report"[4]).

The FAO (2006a) projection results are also briefly presented in a companion paper[5]. They can be considered to represent a baseline scenario but do not take into account additional demand for agricultural products and for land needed in biofuel production nor do they explicitly account for land use changes due to climate change. This is not to say that such demands on agriculture would be additive to demand on agriculture and natural resources for food and feed purposes. There will be competition for resources and substitution among the final uses of agricultural products. These issues will be discussed in another paper for this meeting by G. Fischer[6].

In discussing the natural resource implications, this paper will mainly focus on the physical dimensions of natural resource use in agriculture. While acknowledging the validity and importance of environmental and sustainability concerns such as deforestation, land degradation and water pollution, due to space and time constraints these will not be explicitly dealt with in this paper.

The 2006 study had as base year the three-year average 1999/2001 based on FAOSTAT data as known in 2002-04. At present, FAOSTAT offers published data up to 2003 for supply-utilization accounts and up to 2007 for land use and production by crop, and although due to time constraints and the non-availability of published food balance sheet data after 2003, no new base year and projections could be derived, production and land use data for the latest three-year average 2005/07 were taken into account in the work underlying this paper.

Another limitation is that at the time of preparation of this paper the results of the 2009 Global Agro-Ecological Zone (GAEZ) study were not yet available so that resort had to be taken to the results of the 2002 GAEZ study (as reported in Fischer *et al*., 2002).

This paper is based on analytical work for 146 countries (93 developing and 53 developed countries[7], 42 of the latter grouped into 4 country groups. See the Appendix). These countries cover at present almost 98 and 100 percent of the world's population and arable land respectively.

## HOW MUCH MORE NEEDS TO BE PRODUCED?

FAO's 2006 baseline projections (FAO, 2006a) show that by 2050 the world's average daily calorie availability could rise to 3130 kcal per person, an 11 percent increase over its level in 2003. This would by 2050 still leave some 4 percent of the developing countries' population chronically undernourished[8].

For these projections to materialize, world agricultural production would need to increase by some 70 percent over the period from 2005/07 to 2050 (see Table 1). World population is projected to rise by some 40 percent over this period, meaning that per caput production would rise by some 22 percent. The fact that this would translate into an only 11 percent increase of per caput calorie availability is mainly[9] due to the expected changes in diet, i.e. a shift to higher value foods of often lower calorie content (e.g. vegetables and fruits) and to livestock products which imply an inefficient conversion of calories of the crops used in livestock feeds. Meat consumption per caput for example would rise from 37 kg at present to 52 kg in 2050

4 Unlike the preceding study (Bruinsma, 2003), the 2006 interim study did for a number of reasons not deal with resource use issues such as of land and yield expansion and water use in irrigation.

5 Alexandratos, N. (2009), "World food and agriculture to 2030/2050: Highlights and views from mid-2009".

6 Fischer, G. (2009), "World food and agriculture to 2030/50: how do climate change and bioenergy alter the long-term outlook for food, agriculture and resource availability?".

7 The developed countries include the industrialized countries and the 'countries in transition'.

8 A partial update of the projections presented in Alexandratos (2009) shows a lower average calorie availability by 2050 of 3050 kcal per person per day and a slightly higher share of the developing countries' population chronically undernourished, namely 5 percent.

9 Since total agricultural production is measured by weighing individual products with average international prices, the price-based index of the volume of production grows faster than aggregates expressed in physical units or using a calorie-based index as diets change away from staples to higher value commodities (see Box 3.1 in FAO, 2006a).

(from 26 to 44 kg in the developing countries) implying that much of the additional crop (cereal) production will be used for feeding purposes in livestock production.

**Table 1: Increases in agricultural production, past and future**

| | 1961/63 | 2005/07 | 2050 | 1961/63 to 2005/07 | 2005/07 to2050 |
|---|---|---|---|---|---|
| | million tonnes / persons | | | increment in percent | |
| **World (146 countries)** | | | | | |
| population# | 3133 | 6372 | 8796 | 103 | 38 |
| total production* | | | | 148 | 70 |
| crop production* | | | | 157 | 66 |
| cereals** | 843 | 2012 | 3009 | 139 | 49 |
| livestock production* | | | | 136 | 76 |
| meat production | 94 | 249 | 461 | 165 | 85 |
| **(93) Developing countries** | | | | | |
| population | 2139 | 5037 | 7433 | 135 | 48 |
| total production | | | | 255 | 97 |
| crop production | | | | 242 | 82 |
| cereals | 353 | 1113 | 1797 | 215 | 61 |
| livestock production | | | | 284 | 117 |
| meat production | 42 | 141 | 328 | 236 | 132 |
| **(53) Developed countries** | | | | | |
| population | 994 | 1335 | 1362 | 34 | 2 |
| total production | | | | 63 | 23 |
| crop production | | | | 64 | 30 |
| cereals | 490 | 900 | 1212 | 84 | 35 |
| livestock production | | | | 62 | 17 |
| meat production | 52 | 108 | 133 | 108 | 23 |

# 2005/07 = 2005; 2050 from the UN 2002 Assessment; the 2050 projection from the UN 2008 Assessment amounts to 9056 million for the 146 countries covered.
* in value terms.
** including rice in milled form. The latest (CCBS) data show a world cereal production of 2138 million tons for 2006/08 implying an increment to 2050 of less than 900 million ton if measured from the 2006/08 average.

Table 1 shows the increments in production for the past and future 44-year periods. It clearly brings out the drastic slowdown in expected production growth as compared with the past for the country and commodity groups shown. This of course mirrors the projected deceleration in demand for agricultural products which in turn is a reflection of the decelerating growth of population and of the fact that an ever increasing share of population gradually attains mid to high levels of food consumption (FAO, 2006a).

This slowdown is particularly pronounced for the group of developed countries, but the group of better-off developing countries (defined as having a 2005 daily calorie supply of over 3000 kcal per person) is expected to follow a similar pattern.

**Table 2: Annual crop production growth (percent p.a.)**

| | 1961-07 | 1987-07 | 1997-07 | 2005/07-30 | 2030-50 | 2005/07-50 |
|---|---|---|---|---|---|---|
| Developing countries | 3.0 | 3.0 | 2.9 | 1.5 | 0.9 | 1.2 |
| idem, excl. China and India | 2.7 | 2.8 | 3.1 | 1.8 | 1.3 | 1.6 |
| sub-Saharan Africa | 2.5 | 3.2 | 2.9 | 2.5 | 1.7 | 2.1 |
| Near East / North Africa | 2.6 | 2.3 | 2.1 | 1.7 | 1.0 | 1.4 |
| Latin America and Caribbean | 2.6 | 2.9 | 3.6 | 2.1 | 1.3 | 1.8 |
| South Asia | 2.6 | 2.2 | 2.0 | 1.6 | 0.9 | 1.3 |
| East Asia | 3.5 | 3.4 | 3.3 | 1.0 | 0.5 | 0.8 |
| Developed countries | 0.9 | 0.2 | 0.7 | 0.9 | 0.4 | 0.7 |
| World | 2.2 | 2.1 | 2.2 | 1.3 | 0.8 | 1.1 |
| 14 developing countries with over 3000 kcal/person/day in 2005* | 3.3 | 3.3 | 3.2 | 1.3 | 0.7 | 1.0 |

* these countries account for 40 percent of the population in developing countries

Although the annual growth of world agricultural production is projected to fall from 2.2 percent over the last decade to 1.5 percent over the period to 2030 and 0.9 percent over the period 2030 to 2050 (Table 2), one should not lose sight of the fact that the incremental quantities involved are still very considerable: an additional billion tonnes of cereals and an another 200 million tonnes of meat would need to be produced annually by 2050. The latter would require ample increases in the production of concentrate feeds. For example, some 80 percent of the additional 480 million tons of maize produced annually by 2050 would be for animal feeds and soybean production would need to increase by a hefty 140 percent to 515 million tons in 2050. As mentioned before, these increments do not account for additional production needed as feedstock in biofuel production.

With a view to natural resource use in agricultural production, one should bear in mind that the bulk of the foods consumed are produced locally. On average at present only 16 percent[10] (15 percent for cereals and 12 percent for meats) of world production enters international trade, with of course a wide variation among individual countries and commodities.

## WHAT ARE THE SOURCES OF GROWTH IN CROP PRODUCTION?

Growth in crop production comes on account of growth in crop yields and/or expansion in the physical area (arable land) allocated to crops which, together with increases in cropping intensities (i.e. by increasing multiple cropping and/or shortening of fallow periods), leads to an expansion in the actually harvested area.

For the purposes of this study, a detailed investigation was made of present and future land/yield combinations for 34 crops under rainfed and irrigated cultivation conditions, for 108 countries and country groups. The informal method applied took into account whatever information was available but is in the main based on expert-judgment (see Box 1 for a brief description of the approach followed).

The summary results shown in Table 3 should be taken as rough indications only. For example, yields here are weighted yields (international price weights) for 34 crops, historical data for arable land are unreliable for many countries, data on cropping intensities for most countries are non-existent and for this study were derived by comparing data on harvested land, aggregated over all crops, with data on arable land, and so on.

About 80 percent of the projected growth in crop production in developing countries would come from intensification in the form of yield increases (71 percent) and higher cropping intensities (8 percent, Table 3). The share due to intensification goes up to 95 percent in the land-scarce region South Asia and to over 100 percent in Near East/North Africa where increases in yield would have to also compensate for the foreseen decline in the arable land area. Arable land expansion will remain an important factor in crop production growth in many countries of sub-Saharan Africa and Latin America although less so than in the past.

**Table 3: Sources of growth in crop production (percent)**

| | **Arable land expansion** | | **Increases in cropping intensity** | | **Yield increases** | |
|---|---|---|---|---|---|---|
| | **1961 - 2005** | **2005/07 -2050** | **1961 - 2005** | **2005/07 -2050** | **1961 - 2005** | **2005/07 -2050** |
| All developing countries | 23 | 21 | 8 | 8 | 70 | 71 |
| sub-Saharan Africa | 31 | 25 | 31 | 6 | 38 | 69 |
| Near East/North Africa | 17 | -7 | 22 | 17 | 62 | 90 |
| Latin America and Caribbean | 40 | 30 | 7 | 18 | 53 | 52 |
| South Asia | 6 | 5 | 12 | 8 | 82 | 87 |
| East Asia | 28 | 2 | -6 | 12 | 77 | 86 |
| World | 14 | 9 | 9 | 14 | 77 | 77 |
| developing countries with less then 40 percent of their potentially arable land in use in 2005* | | 30 | | 15 | | 55 |
| developing countries with over 80 percent of their potentially arable land in use in 2005** | | 2 | | 9 | | 89 |

* 42 countries accounting for 15 percent of the population in developing countries.
** 19 countries accounting for 35 percent of the population in developing countries.

10 Measured as ((gross imports + gross exports) / 2) / production.

These summary results mask of course a wide variation among countries. The actual combination of the factors used in crop production (e.g. land, labour and capital) in the different countries will be determined by their relative prices. Taking the physical availability of land as a proxy for its relative scarcity and hence price, one would expect land to play a greater role in crop production the less scarce it is. For the 42 developing countries, which at present use less than 40 percent of their land estimated to have some rainfed crop production potential, arable land expansion is projected to account for almost one-third of their crop production growth. At the other end of the spectrum, in the group of 19 land-scarce countries (defined here as countries with more than 80 percent of their suitable land already in use), the contribution of further land expansion to crop production growth is estimated to be almost nil (two percent – see Table 3).

In the developed countries, the area of arable land in crop production peaked in the late 1960s, then remained stagnant for some time and has been declining since the mid-1980s. Hence growth in crop yields accounted for all of their growth in crop production and in addition compensated for declines in their arable land area. This trend is foreseen to continue also for the period to 2050 (see below). As a result, intensification (higher yields and more intensive use of land) is seen to contribute over the projection period more than 90 percent to growth in crop production at the world level.

It is interesting to see that growth in rice production in the developing countries increasingly will have to come (at least on average) entirely from gains in yield (Table 4), with yield increases even compensating for a slight decline in harvested land allocated to rice. This could be a sign of consumption of certain food commodities in some countries reaching saturation levels by 2050.

In the developing countries, the bulk of wheat and rice is produced in the land-scarce regions of Asia and the Near East/North Africa while maize is the major cereal crop in sub-Saharan Africa and Latin America, regions where many countries still have room for area expansion. Expansion of harvested land therefore will continue to be major contributor to production growth of maize.

**Table 4: Sources of growth for major cereals in developing countries**

| | | annual growth (percent p.a.) | | | contribution to growth (percent) | |
|---|---|---|---|---|---|---|
| | | production | harvested land | yield | harvested land | yield |
| Wheat | 1961-2007 | 3.77 | 1.04 | 2.70 | 28 | 72 |
| | 2005/07-2050 | 1.05 | 0.29 | 0.75 | 28 | 72 |
| Rice, paddy | 1961-2007 | 2.32 | 0.51 | 1.80 | 22 | 78 |
| | 2005/07-2050 | 0.48 | -0.11 | 0.59 | -23 | 123 |
| Maize | 1961-2007 | 3.43 | 0.99 | 2.42 | 29 | 71 |
| | 2005/07-2050 | 1.41 | 0.63 | 0.78 | 44 | 56 |

As discussed in FAO (2006a), an increasing share of the increment in the production of cereals, mainly coarse grains, will be used in livestock feed. As a result, maize production in the developing countries is projected to grow at 1.4 percent p.a. against 1.1 percent for wheat and 'only' 0.5 percent for rice. Such contrasts are particularly marked in China where wheat production is expected to grow only marginally and rice production actually falling over the projection period, while maize production is expected to grow by some 60 percent. Hence there will be a corresponding decline in the areas allocated to wheat and rice but a considerable increase in the maize area.

**Table 5: Shares of irrigated land and production in total**

| | **All crops** | | | **Cereals** | |
|---|---|---|---|---|---|
| shares (in percent) | arable land | harvested land | production | harvested land | production |
| World | | | | | |
| share in 2005/07 | 15 | 23 | 42 | 29 | 42 |
| share in 2050 | 16 | 24 | 43 | 30 | 43 |
| Developing countries | | | | | |
| share in 2005/07 | 19 | 29 | 47 | 39 | 59 |
| share in 2050 | 20 | 30 | 47 | 41 | 60 |

This study made an attempt to unfold crop production by rainfed and irrigated land in order to analyse the contribution of irrigated crop production to total crop production. It is estimated that at present in the developing countries, irrigated agriculture, with about a fifth of all arable land, accounts for 47 percent of all crop production and almost 60 percent of cereal production (Table 5). It should be emphasized that except for some major crops in some countries, there is only limited data on irrigated land and production by crops and the results presented in Table 5 are in part based on expert-judgment (see Box 1). Nevertheless, the results suggest a continuing importance of irrigated agriculture.

## Box 1. Projecting land use and yield growth

This box gives a brief account of the approach followed in making projections for land use and future yield levels.

These projections took as a starting point the crop production projections for 2030 and 2050 from the 2006 FAO study "World agriculture: towards 2030/2050" (FAO, 2006a). The crop production projections are based on demand and trade projections (including for livestock and feed commodities) which together make up consistent commodity balances and clear the world market. The baseline scenario presents a view of how the key food and agricultural variables may evolve over time, not how they should evolve from a normative perspective to solve problems of nutrition and poverty. An effort was made to draw to the maximum extent possible on FAO's in-house knowledge available in the various disciplines present in FAO. The quantitative analysis and projections were therefore carried out in considerable detail, also in order to provide a basis for making statements about the future concerning individual commodities and groups of commodities as well as agriculture as a whole, and for any desired group of countries. The analysis was carried out for as large a number of individual commodities and countries as practicable (108 countries and country groups covering some 146 countries in total, 34 crops - see the Appendix for a full list- and two land classes, rainfed and irrigated agriculture).

A major part of the data preparation work is the unfolding of the data for production (i.e. the FAOSTAT data for area harvested and average yield for each crop and country for the three-year average 2005/07, converted into the crop classification used in this study) into its constituent components of area, yield and production for rainfed and irrigated land. Such detailed data are not generally available in any standard database. It became therefore necessary to piece them together from fragmentary information, from both published (e.g. from EUROSTAT for the EU countries) and unpublished documents giving, for example, areas and yields by irrigated and rainfed land at the national level or by administrative districts, supplemented by a good deal of guesstimates. For a number of countries (e.g. for China, EU15, India, Indonesia and the United States of America) the data for irrigated agriculture were assembled at the sub-national level.

No data exist on total harvested land, but a proxy can be obtained by summing up the harvested areas reported for the different crops. Data are available for total arable land in agricultural use (physical area, called in FAOSTAT "arable land and land under permanent crops"). It is not known whether these two sets of data are compatible with each other, but this can be evaluated indirectly by computing the cropping intensity, i.e. the ratio of harvested area to arable land. This is an important parameter that can signal defects in the land use data. Indeed, for several countries (in particular for sub-Saharan countries but not only) the implicit values of the cropping intensities did not seem to be realistic. In such cases the harvested area data resulting from the crop statistics were accepted as being the more robust (or the less questionable) ones and those for arable area were adjusted (see Alexandratos, 1995 for a discussion of these problems) .

Data reported in FAOSTAT on arable irrigated land refer to 'area equipped for irrigation'. What is needed is the 'irrigated land actually in use' which is often between 80 and 90 percent of the area equipped. Data for the 'area in use' were taken from FAO's AQUASTAT database.

The bulk of the projection work concerned the unfolding of the projected crop production for 2030 and 2050 into (harvested) area and yield combinations for rainfed and irrigated land, and making projections for total arable land and arable irrigated area in use.

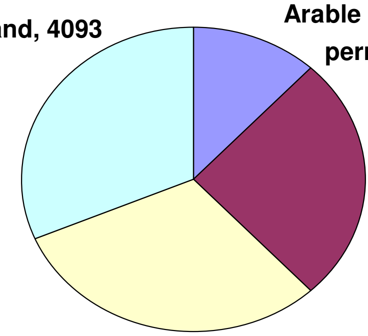
An initial mechanically derived projection for rainfed and irrigated harvested area and yield by crop (constrained to arrive at exactly the projected production) was evaluated against such information as recent growth in land and yield (total by crop) and the 'attainable yield' levels for most crops from the Global Agro-Ecological Zone (GAEZ) study (Fischer *et al.*, 2002), and adjusted were needed. A similar projection was made for total arable rainfed and irrigated area which were then evaluated against estimates for the (maximum) potential areas for rainfed agriculture (from the GAEZ) and for irrigated agriculture (from AQUASTAT) and adjusted where needed. In addition, for irrigated areas cropping patterns were checked against and made to obey certain cropping calendars (i.e. not all crops can be grown in all months of the year). A final step was to derive the implicit cropping intensities for rainfed and irrigated agriculture (by comparing harvested land over all crops with the arable area) and again adjusting areas (and yields) where needed. Normally it required several iterations before arriving at an 'acceptable' picture of the future.

Since the whole exercise is dependent on expert-judgment and requires an evaluation of each and every number, it is a time-consuming exercise. The projections presented in this study are not trend extrapolations as they take into account all knowledge available at present as to expected developments that might make evolutions in major variables deviate from their trend path.

## BY HOW MUCH DOES THE ARABLE LAND AREA NEED TO INCREASE?

At present some 12 percent (over 1.5 billion ha. Figure 2) of the globe's land surface (13.4 billion ha) is used in crop production (arable land and land under permanent crops). This area represents slightly over a third (36 percent) of the land estimated to be to some degree suitable for crop production. The fact that there remain some 2.7 billion ha with crop production potential suggests that there is still scope for further expansion of agricultural land. However, there is also a perception, at least in some quarters, that there is no more, or very little, land to bring under cultivation. In what follows, an attempt is made to shed some light on these contrasting views by first briefly discussing some estimates of land with crop production potential and some constraints to exploiting such suitable areas, where after the projected expansion of the agricultural area over the period up to 2050 will be presented.

**Figure 2: World land area (million ha in 2005)**




Source: FAOSTAT

### How much land is there with crop production potential[11]?

Notwithstanding the predominance of yield increases in the growth of agricultural production, land expansion will continue to be a significant factor in those developing countries and regions where the potential for expansion exists and the prevailing farming systems and more general demographic and socio-economic conditions favour it. One of the frequently asked questions in the debate on world food futures and sustainability is: how much land is there that could be used to produce food to meet the needs of the growing population?

The Global Agro-Ecological Zone (GAEZ) study published in 2002 (Fischer *et al*., 2002), combining soil, terrain and climate characteristics with crop production requirements, estimates for each land grid cell at the arc minute level, suitability (in terms of land extents and attainable yield levels) for crop production at three input levels (low, intermediate and high).

Summing over all crops (covered in the GAEZ) and technology levels considered, it is estimated that about 30 percent of the world's land surface, or 4.2 billion ha[12] is suitable to some extent for rainfed agriculture

[11] This section is an adaptation of a similar section in Bruinsma (2003). It is based on the Global Agro-Ecological Zone (GAEZ) published in 2002 (Fischer *et al*., 2002). During the past few years the GAEZ study was completely revisited, results of which will be published during 2009, unfortunately too late to be taken into account in the work for this paper.

(Table 6). Of this area some 1.6 billion ha are already under cultivation (Table 7). The developing countries have some 2.8 billion ha of land of varying qualities which have potential for growing rainfed crops at yields above an "acceptable" minimum level, of which nearly 970 million ha are already under cultivation. The gross land balance of 2.6 billion ha (4.2 – 1.6 billion; 1.8 billion ha for the developing countries) would therefore seem to provide significant scope for further expansion of agriculture. However, this favourable impression must be much qualified if a number of considerations and constraints are taken into account.

**Table 6: Land with rainfed crop production potential (million hectares)**

| | Total land surface | Share of land suitable (%) | Total land suitable | Very suitable (VS)* | Suitable (S) | Moderately suitable (MS) | Marginally suitable (mS) | Not suitable (NS) |
|---|---|---|---|---|---|---|---|---|
| Developing countries | 7302 | 38 | 2782 | 1109 | 1001 | 400 | 273 | 4520 |
| Sub-Saharan Africa | 2287 | 45 | 1031 | 421 | 352 | 156 | 103 | 1256 |
| Near East/North Africa | 1158 | 9 | 99 | 4 | 22 | 41 | 32 | 1059 |
| Latin America | 2035 | 52 | 1066 | 421 | 431 | 133 | 80 | 969 |
| South Asia | 421 | 52 | 220 | 116 | 77 | 17 | 10 | 202 |
| East Asia | 1401 | 26 | 366 | 146 | 119 | 53 | 48 | 1035 |
| Industrial countries | 3248 | 27 | 874 | 155 | 313 | 232 | 174 | 2374 |
| Transition countries | 2305 | 22 | 497 | 67 | 182 | 159 | 88 | 1808 |
| World** | 13400 | 31 | 4188 | 1348 | 1509 | 794 | 537 | 9211 |

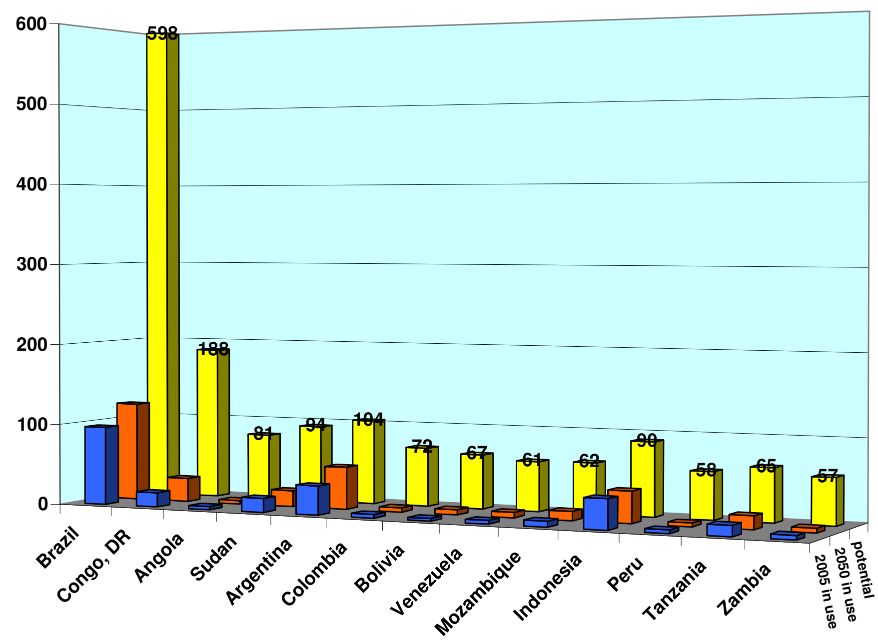
* VS = yield attainable is 80 to 100 percent of the maximum constraint-free yield; S = 60-80%; MS = 40-60%; mS = 20-40%; NS = <20%.
** Including some countries not covered in this study.

First, it ignores land uses other than for growing the crops for which it was evaluated. Thus, forest cover, protected areas and land used for human settlements and economic infrastructure are not taken into account. Alexandratos (1995) estimated that forests cover at least 45 percent, protected areas some 12 percent and human settlements some 3 percent of the gross land balance so that the net land balance for developing countries would be only 40 percent of the gross balance. Naturally there are wide regional differences. For example, in the land-scarce region of South Asia, some 45 percent of the land with crop production potential but not yet in agricultural use, is estimated to be occupied by human settlements. This leaves little doubt that population growth and further urbanization will be a significant factor in reducing land availability for agricultural use in this region. A more recent estimate by Nachtergaele and George (2009) shows that at the world level urban areas take up some 60 million ha of the gross land balance, protected areas 200 million ha and forests 800 million ha, so that the net land balance would be some 1.5 billion ha.

Second and probably more important than allowing for non-agricultural use of land with crop production potential is the nature of the estimates itself, i.e. the method of deriving the land suitability estimates: it is enough for a piece of land to support a single crop at a minimum yield level for it to be classified as 'suitable' land. For example, large tracts of land in North Africa permit cultivation of only olive trees (and a few other minor crops). These areas therefore are counted as 'suitable' although one might have little use for them in practice. It is therefore more sensible to discuss suitability for individual crops and the notion of an overall land suitability is of limited meaning.

[12] Fischer (2002) reports a lower 3.56 billion ha (Table 5.15) for the gross extent of land with rainfed crop production potential which is based on a different version of the GAEZ 2002 as used in Bruinsma (2003). Likewise OECD/FAO (2009) also basing itself on the GAEZ 2002, reports a total of 4.3 billion ha for the gross extent of land with rainfed crop production potential.

**Figure 3: Developing countries with the highest (gross) land balance**




Note: thirteen countries with a gross land balance of over 50 million ha in 2005 and accounting for two-thirds of the total gross land balance in developing countries.

Third, the land balance (land with crop production potential not in agricultural use) is very unevenly distributed between regions and countries. Some 90 percent of the remaining 1.8 billion ha in developing countries is in Latin America and sub-Saharan Africa, and half of the total is concentrated in just seven countries (Brazil, Democratic Republic of the Congo, Angola, Sudan, Argentina, Colombia, Bolivia. See Figure 3). At the other extreme, there is virtually no spare land available for agricultural expansion in South Asia and the Near East/North Africa. In fact, in a few countries in these latter two regions, the land balance is negative, i.e. land classified as not suitable, is made productive through human intervention such as terracing of sloping land, irrigation of arid and hyper-arid land, etc., and is in agricultural use. Even within the relatively land-abundant regions, there is great diversity of land availability, in terms of both quantity and quality, among countries and sub-regions.

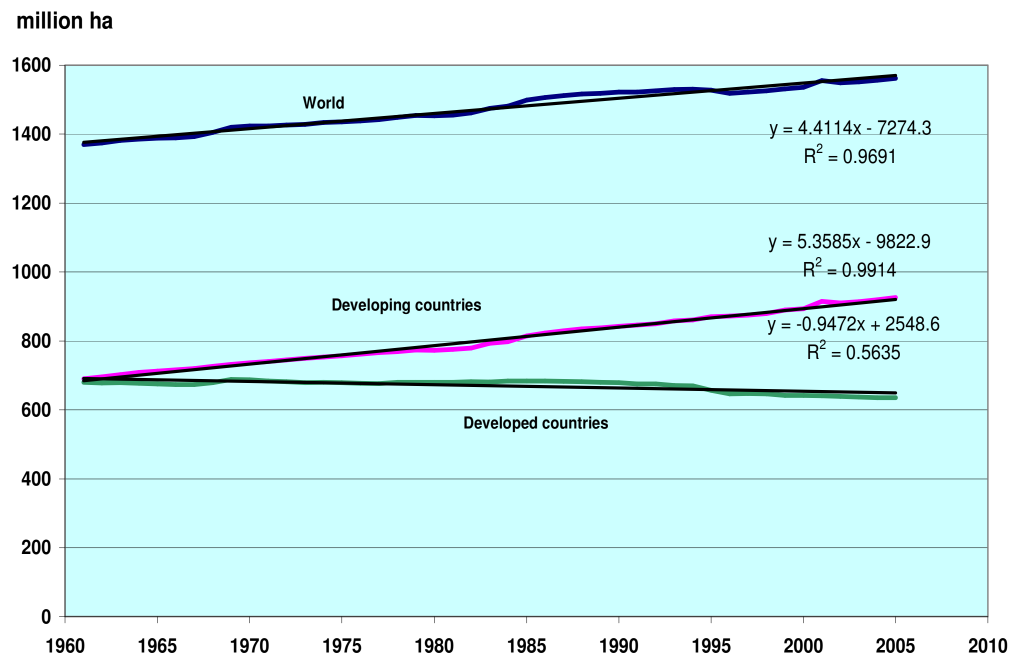
Fourth, much of the remaining land also suffers from constraints such as ecological fragility, low fertility, toxicity, high incidence of disease or lack of infrastructure. These reduce its productivity, require high input use and management skills to permit its sustainable use, or require prohibitively high investments to be made accessible or disease-free. Fischer (2002) shows that over 70 percent of the land with rainfed crop production potential in sub-Saharan Africa and Latin America suffers from one or more soil and terrain constraints. Natural causes as well as human intervention can also lead to deterioration of the productive potential of the resource for example through soil erosion or salinization of irrigated areas. Hence the evaluation of suitability may contain elements of overestimation (see also Bot *et al.*, 2000) and much of the land balance cannot be considered to be a resource that is readily usable for food production on demand.

These considerations underline the need to interpret estimates of land balances with caution when assessing land availability for agricultural use. Cohen (1995) summarizes and evaluates all estimates made of available cultivable land, together with their underlying methods, and shows their extremely wide range. Young (1999) offers a critique of the estimates of available cultivable land, including those given in Alexandratos (1995), stating that they often represent gross over-estimates.

## Expansion of land in crop production

The perception that there is no more, or very little, new land to bring under cultivation might be well grounded in the specific situations of land-scarce countries and regions such as South Asia and the Near East/North Africa but may not apply, or may apply with much less force, to other parts of the world. As discussed above, there are large tracts of land with varying degrees of agricultural potential in several countries, most of them in sub-Saharan Africa and Latin America with some in East Asia. However, this land may lack infrastructure, be partly under forest cover or in wetlands which should be protected for environmental reasons, or the people who would exploit it for agriculture lack access to appropriate technological packages or the economic incentives to adopt them.

**Figure 4: Arable land and land under permanent crops: past developments**




In reality, expansion of land in agricultural use continues to take place (Figure 4). It does so mainly in countries which combine growing needs for food and employment with limited access to technology packages that could increase intensification of cultivation on land already in agricultural use. The data show that expansion of arable land continues to be an important source of agricultural growth in sub-Saharan Africa, Latin America and East Asia (Table 7). This includes countries with ample land resources with potential for crops facing fast demand growth, particularly for exports and for non-food uses, e.g. soybeans in South America and the oilpalm in South-East Asia. Indeed, oilcrops have been responsible for a good part of the increases in total cultivated land in the developing countries and the world as a whole (FAO, 2006a), albeit often at the expense of deforestation.

The projected expansion of arable land in crop production shown below in Tables 7, 8 and 9, has been derived for rainfed and irrigated land separately. As explained in Box 1, starting with the production projections for each crop, the land and yield projections were derived drawing on expert judgement and taking into account: (a) base year (2005/07) data on total harvested land and yield by crop; (b) data or often estimates for harvested land and yield by crop for rainfed and irrigated land; (c) data on total arable rainfed and irrigated land and their expected increases over time; (d) likely increases in yield by crop and land class; (e) plausible increases in cropping intensities, and (g) the land balances for rainfed and irrigated agriculture. As mentioned in Box 1, base year data for total arable land were for several developing countries adjusted (in particular for China[13]) to, among other things, arrive at cropping intensities that seemed more meaningful. This is reflected in column '2005 adj.' in Table 7.

**Table 7: Total arable land: data and projections**

| | **arable land in use** | | | | | | **annual growth** | | | **balance** | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **1961 /63** | **1989 /91** | **2005** | **2005 adj.** | **2030** | **2050** | **1961-2005** | **1990-2005** | **2005-2050** | **2005** | **2050** |
| | (million ha) | | | | | | (percent p.a.) | | | (million ha) | |
| sub-Saharan Africa | 133 | 161 | 193 | 236 | 275 | 300 | 0.80 | 1.07 | 0.55 | 786 | 723 |
| Latin America | 105 | 150 | 164 | 203 | 234 | 255 | 1.01 | 0.64 | 0.52 | 861 | 809 |
| Near East/ North Africa | 86 | 96 | 99 | 86 | 84 | 82 | 0.34 | -0.02 | -0.11 | 13 | 16 |
| South Asia | 191 | 204 | 205 | 206 | 211 | 212 | 0.15 | 0.07 | 0.07 | 14 | 7 |
| East Asia | 178 | 225 | 259 | 235 | 236 | 237 | 0.99 | 1.12 | 0.02 | 131 | 129 |
| excl. China | 73 | 94 | 102 | 105 | 109 | 112 | 0.85 | 0.71 | 0.15 | 78 | 75 |
| Developing countries | 693 | 837 | 920 | 966 | 1040 | 1086 | 0.67 | 0.65 | 0.27 | 1805 | 1684 |
| excl. China and India | 426 | 536 | 594 | 666 | 740 | 789 | 0.75 | 0.66 | 0.39 | 1730 | 1609 |
| Industrial countries | 388 | 401 | 388 | 388 | 375 | 364 | -0.02 | -0.21 | -0.15 | 486 | 510 |
| Transition countries | 291 | 277 | 247 | 247 | 234 | 223 | -0.32 | -0.90 | -0.23 | 250 | 274 |
| World | 1375 | 1521 | 1562 | 1602 | 1648 | 1673 | 0.30 | 0.17 | 0.10 | 2576 | 2503 |

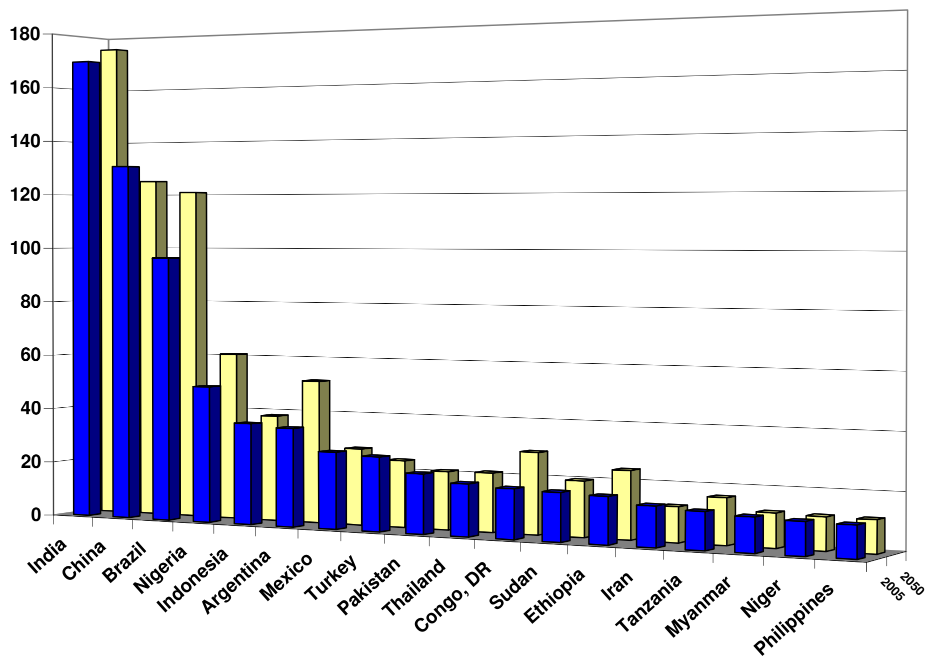
Source for historical data: FAOSTAT, January 2009. "World" includes a few countries not included in the other country groups shown.

The overall result for developing countries is a projected net increase in the arable area of some 120 million ha (from 966 in the base year to 1086 in 2050), an increase of 12.4 percent (see Table 7). Not surprisingly, the bulk of this projected expansion is expected to take place in sub-Saharan Africa (64 million) and Latin America (52 million), with almost no land expansion in East and South Asia, and even a small decline in Near East/North Africa. The slowdown in the expansion of arable land is mainly a consequence of the projected slowdown in the growth of crop production and is common to all regions.

The bulk of arable land in use is concentrated in a small number of developing countries (Figure 5). A number of developing countries would towards the end of the projection period witness a decline in the arable land area (e.g. China and the Republic of Korea, but not only) and embark on a pattern already seen for most developed countries (with production only increasing very slowly and increases in yield permitting a reduction in crop area).

[13] Data on arable land for China are unreliable. FAOSTAT data show an (unlikely) upward trend from 1983 onwards, which distorts the historical growth rates in Table 7 for East Asia (and for the total of developing countries).

**Figure 5: Developing countries with over 10 million ha of arable land in use***



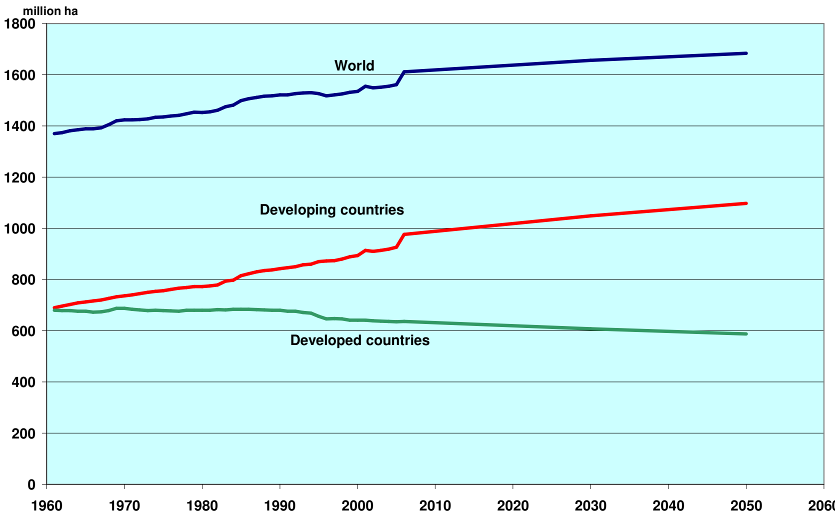

* These 18 countries account in 2005 for 75 percent of the total arable land in use in developing countries

The arable area in the world as a whole expanded between 1961/63 and 2005 by 187 million ha, the result of two opposite trends: an increase of 227 million ha in the developing countries and a decline of 40 million ha in the developed countries. The arable land area in the latter group of countries peaked in the mid-1980s (at 684 million ha) and declined ever since. This decline in the arable area has been accelerating over time (Table 7). The longer-term forces determining such declines are sustained yield growth combined with a continuing slowdown in the growth of demand for their agricultural products. The projections of this study foresee a further slow decline in their arable area to 587 million ha in 2050 (it is again noted that this may change under the impact of an eventual fast growth in biofuels). The net result for the world is an increase in the arable land area of 71 million ha, consisting of an increase by 120 million ha in the developing countries and a decline by 48 million ha in the developed countries (Table 7 and Figure 6).

Arable land in the group of land-scarce countries[14] would practically remain constant (at between 265 and 268 million ha), but its irrigated land could expand by some 12 million ha of which 9 million ha through conversion of rainfed land. Some of these countries are still highly dependent on agriculture and experiencing an above-average population growth, which combined with their resource constraints, could make solving their food security problems extremely cumbersome if not impossible, at least without external assistance and/or by finding non-agricultural development opportunities (Alexandratos, 2005).

[14] 19 countries with more than 80 percent of their land with rainfed and/or irrigation potential in use in 2005, of which 6 are in the Near East / North Africa, 5 in sub-Saharan Africa and 4 in South Asia.

**Figure 6: Arable land and land under permanent crops: past and future**




The projected average annual increase in the developing countries' arable area of 2.75 million ha (120 million ha over 44 years) is a net increase. It is the total of gross land expansion minus land taken out of production for various reasons, for example due to degradation, loss of economic viability or conversion to settlements. An unknown part of the new land to be brought into agriculture will come from land currently under forests. If all the additional land would come from forested areas, this would imply an annual deforestation rate of 0.14 percent, compared with 0.42 percent (or 9.3 million ha p.a.) for the 1990s and 0.36 percent (or 7.5 million ha p.a.) over the period 2000 to 2005 (FAO, 2006b). The latter estimates, of course, include deforestation from all causes, such as informal, non-recorded agriculture, grazing, logging, gathering of fuel wood, etc.

What does the empirical evidence show concerning land expansion for agricultural use in the developing countries? Micro-level analyses have generally established that under the socio-economic and institutional conditions prevailing in many developing countries, increases in output are, at least initially, obtained mainly through land expansion, where the physical potential for doing so exists. For example, in an analysis of the experience of Côte d'Ivoire, Lopez (1998) concludes that "the main response of annual crops to price incentives is to increase the area cultivated." Similar findings, such as the rate of deforestation being positively related to the price of maize, are reported for Mexico by Deininger and Minten (1999). Some of the land expansion however is taking place at the expense of longer rotation periods and shorter fallows, a practice still common to many countries in sub-Saharan Africa, with the result that the natural fertility of the soil is reduced. Since fertilizer use is often uneconomic, the end-result is soil mining and stagnation or outright reduction of yields.

Although the developing countries' arable area is projected to expand by 120 million ha over the projection period, the harvested area would increase by 160 million ha or 17 percent, due to increases in cropping intensities (Table 8). The overall cropping intensity for developing countries could rise by about four percentage points over the projection period (from 95 to 99 percent). Cropping intensities continue to rise through shorter fallow periods and more multiple cropping. An increasing share of irrigated land in total agricultural land also contributes to more multiple cropping. Almost one-third of the arable land in South and East Asia is irrigated, a share which is projected to rise to over 36 percent in 2050. This high share of irrigation in total arable land is one of the reasons why the average cropping intensities in these regions are considerably higher than in other regions. Average cropping intensities in developing countries, excluding China and India which together account for well over half of the irrigated area in the developing countries, are and will continue to be much lower.

**Table 8: Arable land in use, cropping intensities and harvested land**

| | | Total land in use | | | Rainfed use | | | Irrigated use* | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | A[#] | CI | H | A | CI | H | A | CI | H |
| Developing countries | 2005/07 | 966 | 95 | 919 | 777 | 83 | 649 | 189 | 143 | 270 |
| | 2050 | 1086 | 99 | 1078 | 864 | 87 | 753 | 222 | 147 | 325 |
| excl. China and India | 2005/07 | 666 | 82 | 547 | 582 | 76 | 442 | 84 | 124 | 105 |
| | 2050 | 785 | 89 | 697 | 680 | 83 | 562 | 106 | 129 | 136 |
| Developed countries | 2005/07 | 635 | 74 | 473 | 584 | 72 | 422 | 51 | 100 | 51 |
| | 2050 | 587 | 81 | 478 | 536 | 80 | 426 | 51 | 100 | 51 |
| World | 2005/07 | 1602 | 87 | 1392 | 1361 | 79 | 1070 | 240 | 134 | 321 |
| | 2050 | 1673 | 93 | 1556 | 1400 | 84 | 1179 | 273 | 138 | 377 |

# A = arable land (million ha); CI = cropping intensity in percent; H = harvested land (million ha).
* Irrigated area actually in use as distinguished from 'area equipped for irrigation' (Table 9).

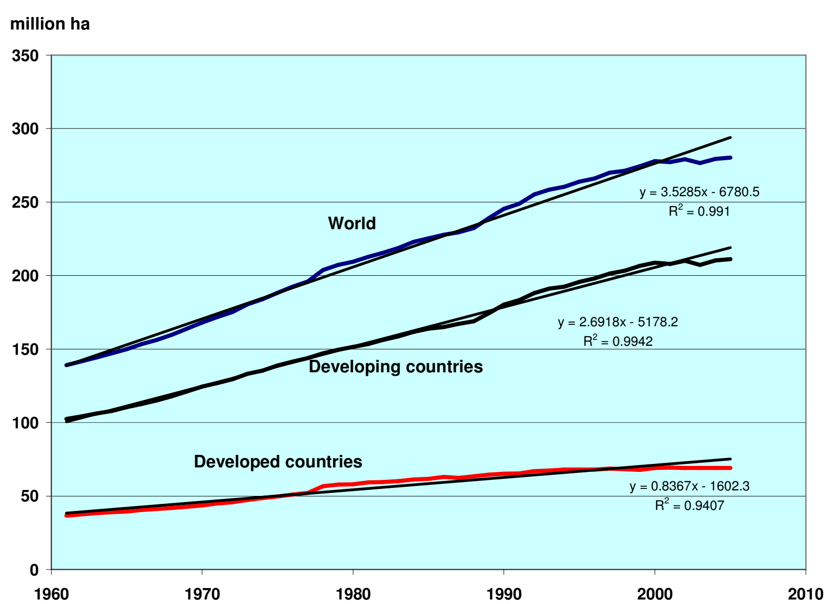
Rising cropping intensities could be one of the factors responsible for increasing the risk of land degradation and thus threatening sustainability, in particular when not accompanied by land conservation measures, including adequate and balanced use of fertilizers to compensate for the removal of soil nutrient by crops. It is expected that this risk will continue to exist because in many cases the socio-economic conditions do not favour the implementation of the technological changes required to ensure the sustainable intensification of land use.

## HOW MUCH MORE WATER WILL BE REQUIRED IN IRRIGATION?

### Expanding irrigated land

The area equipped for irrigation has been continuously expanding (mainly in developing countries and only slowly in developed countries) although more recently this expansion has considerably slowed down (Figure 7). The projections of irrigation presented below reflect scattered information on existing irrigation expansion plans in the different countries, potentials for expansion (including water availability) and need to increase crop production. The projections include expansion in both formal and informal irrigation, the latter being important in particular in sub-Saharan Africa.

**Figure 7: Area equipped for irrigation**



The aggregate result shows that the area equipped for irrigation could expand by 32 million ha (11 percent) over the projection period (Table 9) all of it in the developing countries. This means that some 16 percent of the land with irrigation potential in this group of countries not yet equipped at present could be brought under irrigation, and that by 2050 some 60 percent of all land with irrigation potential[15] (417 million ha) would be in use.

The expansion of irrigation would be strongest (in absolute terms) in the more land-scarce regions hard-pressed to raise crop production through more intensive cultivation practices, such as East Asia (+ 12 million ha), South Asia (+ 8 million ha), and the Near East/North Africa (+ 6 million ha), although in the latter region further expansion will become increasingly difficult as water scarcity increases and competition for water from households and industry will continue to reduce the share available to agriculture. China and India alone account for more than half (56 percent) of the irrigated area in developing countries. Although the overall arable area in China is expected to decrease further, the irrigated area would continue to expand through conversion of rainfed land.

**Table 9: Area equipped for irrigation**

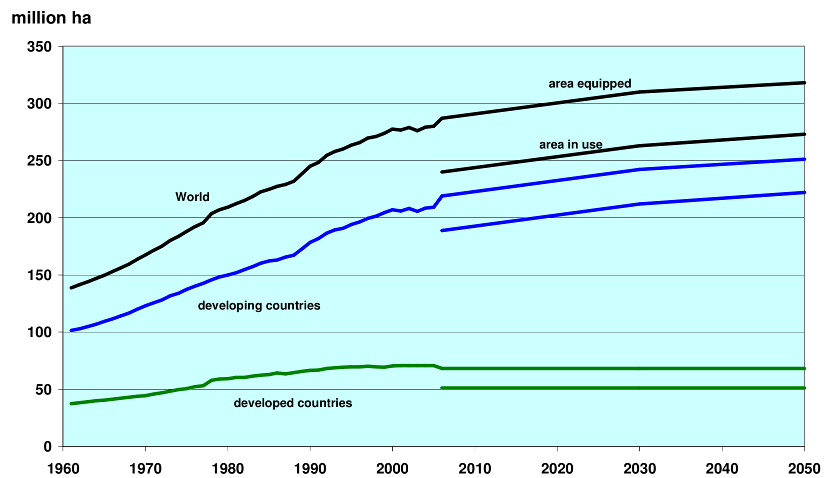
| | **1961/63** | **1989/91** | **2005/07** | **2030** | **2050** | **1961-05** | **1990-05** | **1996-05** | **2005-50** |
|---|---|---|---|---|---|---|---|---|---|
| | **million ha** | | | | | **annual growth (percent p.a.)** | | | |
| Developing countries | 103 | 178 | 219 | 242 | 251 | 1.76 | 1.05 | 0.63 | 0.31 |
| idem, excl. China and India | 47 | 84 | 97 | 111 | 117 | 1.91 | 1.06 | 0.89 | 0.42 |
| sub-Saharan Africa | 2.5 | 4.5 | 5.6 | 6.7 | 7.9 | 2.07 | 1.49 | 0.98 | 0.67 |
| Latin America and Caribbean | 8 | 17 | 18 | 22 | 24 | 2.05 | 0.62 | 0.27 | 0.72 |
| Near East / North Africa | 15 | 25 | 29 | 34 | 36 | 1.86 | 1.21 | 1.30 | 0.47 |
| South Asia | 37 | 67 | 81 | 84 | 86 | 1.98 | 1.10 | 0.28 | 0.14 |
| East Asia | 40 | 64 | 85 | 95 | 97 | 1.42 | 1.00 | 0.80 | 0.30 |
| Developed countries | 38 | 66 | 68 | 68 | 68 | 1.57 | 0.38 | 0.20 | 0.00 |
| World | 141 | 244 | 287 | 310 | 318 | 1.71 | 0.87 | 0.52 | 0.24 |

The developed countries account for almost a quarter of the world's irrigated area, 68 out of 287 million ha (Table 9). Annual growth of their irrigated area reached a peak of 3.0 percent in the 1970s, dropping to 1.1 percent in the 1980s and to only 0.2 percent over the last decade for which data are available (1996-2005). For the developed countries as a group only a marginal expansion of the irrigated area (supplemented with improvements on existing areas) is foreseen over the projection period so that the world irrigation scene will remain dominated by events in the developing countries.

For the purpose of this study a distinction was made between the area equipped for irrigation and the irrigated area actually in use (which is the area to be used in the production analysis). Areas equipped might be temporarily or even permanently out of use for various reasons (including for maintenance, because of degradation of irrigation infrastructure or because the area is not needed in a particular year). The percentage of the area equipped actually in use differs from country to country and could range from a low 60 to a high 100 percent, but on average over all countries is 86 percent (expected to increase very slightly to 88 percent in 2050). So out of the 219 million ha equipped for irrigation in the developing countries in 2005/07, some 189 million ha were assumed to be in use increasing to 222 million ha in 2050 (out of 251 million ha equipped; see also Figure 8).

[15] Estimates of "land with irrigation potential" are difficult to make and such estimates should only be taken as rough indications.

**Figure 8: Arable irrigated area: past and future**




The importance of irrigated agriculture was already discussed in the preceding section. Due to a continuing increase in multiple cropping on both existing and newly irrigated areas, the harvested irrigated area could expand by 56 million ha (or 17 percent) and would account for well over a third of the total increase in harvested land (Table 8).

The projected expansion of irrigated land by 32 million ha is an increase in net terms. It assumes that losses of existing irrigated land due to, for example, water shortages or degradation because of salinization and waterlogging, will be compensated for through rehabilitation or substitution by new areas for those lost. The few existing historical data on such losses are too uncertain and anecdotal to provide a reliable basis for drawing inferences about the future. In investment terms, rehabilitation of existing irrigation schemes will represent the bulk of future expenditure on irrigation: if it is assumed that 2.5 percent of existing irrigation must be rehabilitated or substituted by new irrigation each year, that is, if the average life of irrigation schemes were 40 years, then the total irrigation investment activity over the projection period in the developing countries must encompass some 173 million ha, of which more than four-fifths (141 million ha) would be for rehabilitation or substitution and the balance for net expansion.

The projected net increase in land equipped for irrigation of 32 million ha is less then a quarter of the increase over the preceding 44 years (145 million ha). In terms of annual growth it would be 'only' 0.24 percent, well below the 1.7 percent for the historical period. The projected slowdown which applies to most countries and regions, reflects the projected lower growth rate of crop production combined with the increasing scarcity of suitable areas for irrigation and of water resources in some countries, as well as the rising costs of irrigation investment.

Most of the expansion of irrigated land is achieved by converting land in use in rainfed agriculture into irrigated land. Part of irrigation, however, takes place on arid and hyper-arid (desert) land which is not suitable for rainfed agriculture. It is estimated that of the 219 million ha irrigated at present in developing countries, some 40 million ha are on arid and hyper-arid land which could increase to 43 million ha in 2050. In some regions and countries, irrigated arid and hyper-arid land forms an important part of the total irrigated land presently in use: 19 out of 28 million ha in the Near East/North Africa, and 15 out of 70 million ha in South Asia.

#### Water use in irrigation and pressure on water resources

One of the major questions concerning the future is whether there will be sufficient freshwater to satisfy the growing needs of agricultural and non-agricultural users. Agriculture already accounts for about 70 percent of the freshwater withdrawals in the world and is usually seen as one of the main factors behind the increasing global scarcity of freshwater.

The estimates of the expansion of land under irrigation presented in the preceding section provide a partial answer to this question since the assessment of irrigation potential already takes into account water limitations and since the projections to 2050 assume that agricultural water demand will not exceed available water resources[16].

Renewable water resources available to irrigation and other uses are commonly defined as that part of precipitation which is not evaporated or transpired by plants, including grass and trees, and which flows into rivers and lakes or infiltrates into aquifers. The annual water balance for a given area in natural conditions, i.e. without irrigation, can be defined as the sum of the annual precipitation and net incoming flows (transfers through rivers from one area to another) minus evapotranspiration and runoff.

Table 10 shows the renewable water resources for the world and major regions. Average annual precipitation varies from a low 160 mm per year in the most arid region (Near East/North Africa) to a high precipitation of about 1530 mm per year in Latin America. These figures give an impression of the extreme variability of climatic conditions facing the developing countries, and the ensuing differences observed in terms of water scarcity: those countries suffering from low precipitation and therefore most in need of irrigation are also those where water resources are naturally scarce. In addition, the water balance presented is expressed in yearly averages and cannot adequately reflect seasonal and intra-annual variations. Unfortunately, such variations tend to be more pronounced in arid than in humid climates.

The first step in estimating the pressure of irrigation on water resources is to assess irrigation water requirements and withdrawals. Precipitation provides part of the water crops need to satisfy their transpiration requirements. The soil, acting as a buffer, stores part of the precipitation water and returns it to the crops in times of deficit. In humid climates, this mechanism is usually sufficient to ensure satisfactory growth in rainfed agriculture. In arid climates or during the dry season, irrigation is required to compensate for the deficit due to insufficient or erratic precipitation. *Consumptive water use in irrigation* therefore is defined as the volume of water needed to compensate for the deficit between potential evapotranspiration and effective precipitation over the growing period of the crop. It varies considerably with climatic conditions, seasons, crops and soil types. Consumptive water use in irrigation has here been computed for each country on the basis of the irrigated and harvested areas by crop as estimated for the base year (2005/07) and as projected for 2050 (see Box 2 for a brief explanation of the methodology applied).

However, it is *water withdrawal for irrigation*, i.e. the volume of water extracted from rivers, lakes and aquifers for irrigation purposes, which should be used to measure the impact of irrigation on water resources. Irrigation water withdrawal normally far exceeds the consumptive water use in irrigation because of water lost during transport and distribution from its source to the crops. In addition, in the case of rice irrigation, additional water is used for paddy field flooding to facilitate land preparation and for plant protection and weed control.

*Water use efficiency* is defined as the ratio between the estimated consumptive water use in irrigation and irrigation water withdrawal. Data on country water withdrawal for irrigation has been collected in the framework of the AQUASTAT programme (see e.g. FAO, 2005a and 2005b). Comparison of these data with the consumptive use of irrigation was used to estimate water use efficiency[17] at the country level. For the world, it is estimated that the average water use efficiency was around 44 percent in 2005/07, varying from 22 percent in areas of abundant water resources (sub-Saharan Africa) to 54 percent in South Asia where water scarcity calls for higher efficiencies (Table 10).

[16] The concept of irrigation potential has severe limitations and estimates of irrigation potential can vary over time, in relation to the country's economic situation or as a result of competition for water for domestic and industrial use. Estimates of irrigation potential are based on estimates of renewable water resources, i.e. the resources replenished annually through the hydrological cycle. In those arid countries where mining of fossil groundwater represents an important part of water withdrawal, the area under irrigation is usually larger than the irrigation potential.

[17] It should be noted that although the term 'water use efficiency' implies losses of water between source and destination, not all of this water is actually lost as much flows back into the river basin and aquifers and can be re-used for irrigation.

To estimate the irrigation water withdrawal in 2050, an assumption had to be made about possible developments in the water use efficiency in each country. Unfortunately, there is little empirical evidence on which to base such an assumption. Two factors, however, will have an impact on the development of the water use efficiency: the estimated levels of water use efficiency in the base year and water scarcity[18]. A function was designed to capture the influence of these two parameters, bearing in mind that improving water use efficiency is a very slow and difficult process. The overall result is that efficiency could increase by two percentage points, from 44 percent to 46 percent (Table 10). Such an increase in efficiency would be more pronounced in water scarce regions (e.g. a ten percentage point increase in the Near East/North Africa region) than in regions with abundant water resources (three percentage points or less in Latin America and sub-Saharan Africa). Indeed, it is expected that, under pressure from limited water resources and competition from other uses, demand management will play an important role in improving water use efficiency in water scarce regions. In contrast, in humid areas the issue of water use efficiency is much less relevant and is likely to receive little attention.

**Table 10: Annual renewable water resources and irrigation water withdrawal**

| | Precipi-tation | Renewable water resources* | Water use efficiency ratio | | Irrigation water withdrawal | | Pressure on water resources due to irrigation | |
|---|---|---|---|---|---|---|---|---|
| | | | 2005/07 | 2050 | 2005/07 | 2050 | 2005/07 | 2050 |
| | mm p.a. | cubic km | percent | | cubic km | | percent | |
| Developing countries | 990 | 28000 | 44 | 47 | 2115 | 2413 | 8 | 9 |
| sub-Saharan Africa | 850 | 3500 | 22 | 25 | 55 | 87 | 2 | 2 |
| Latin America /Caribbean | 1530 | 13500 | 35 | 35 | 181 | 253 | 1 | 2 |
| Near East / North Africa | 160 | 600 | 51 | 61 | 347 | 374 | 58 | 62 |
| South Asia | 1050 | 2300 | 54 | 57 | 819 | 906 | 36 | 39 |
| East Asia | 1140 | 8600 | 33 | 35 | 714 | 793 | 8 | 9 |
| Developed countries | 540 | 14000 | 42 | 43 | 505 | 493 | 4 | 4 |
| World | 800 | 42000 | 44 | 46 | 2620 | 2906 | 6 | 7 |

* includes at the regional level 'incoming flows'

At the global level irrigation water withdrawal is expected to grow by about 11 percent, from the current 2620 km3/yr to 2906 km3/yr in 2050 (Table 10), increasing in the developing countries by 14 percent (or 298 km3), offset by a decline in the developed countries of over 2 percent (or 12 km3). The 11 percent increase in irrigation water withdrawal should be seen against the projected 17 percent increase in the harvested irrigated area (from 321 million ha in 2005/07 to 377 million ha in 2050; Table 8). This difference is in part explained by the expected improvement in water use efficiency, leading to a reduction in irrigation water withdrawal per irrigated hectare, and in part due to changes in cropping patterns for some countries such as China, where a substantial shift in the irrigated area from rice to maize production is expected: irrigation water requirements for rice production are usually twice those for maize.

Irrigation water withdrawal in 2005/07 was estimated to account for only six percent of total renewable water resources in the world (Table 10). However, there are wide variations between countries and regions, with the Near East/North Africa region using 58 percent of its water resources in irrigation while Latin America barely uses one percent of its resources. At the country level, variations are even higher. In the base year (2005/07), 11 countries used already more than 40 percent of their water resources for irrigation, a situation which can be considered critical. An additional 8 countries consumed more than 20 percent of their water resources, a threshold sometimes used to indicate impending water scarcity. The situation would worsen over the period to 2050, with two more countries crossing the 40 percent and four countries the 20 percent threshold. If one would add the expected additional water withdrawals needed for non-agricultural use, the picture would not change much since agriculture represents the bulk of water withdrawal.

[18] 'stress' measured as consumptive water use in irrigation as a percentage of renewable water resources.

## Box 2. Estimating irrigation water requirements

The estimation of water balances for any year is based on five sets of data, namely four digital geo-referenced data sets for precipitation (New *et al*., 2002), reference evapotranspiration (FAO, 2004), soil moisture storage properties (FAO, 1998), extents of areas under irrigation (Siebert *et al.*, 2007) and irrigated areas for all major crops for 2005/07 and 2050. The computation of water balances is carried out by grid-cell (each of 5 arc minutes, 9.3 km at the equator) and in monthly time steps. The results can be presented in statistical tables or digital maps at any level of spatial aggregation (country, river basin, etc.). They consist of annual values by grid-cell for the actual evapotranspiration, water runoff and consumptive water use in irrigation.

For each grid-cell, the actual evapotranspiration is assumed to be equal to the reference evapotranspiration ($ET_0$, in mm; location-specific and calculated with the Penman-Monteith method; Allen *et al.,* 1998, New *et al.,* 2000) in those periods of the year when precipitation exceeds reference evapotranspiration or when there is enough water stored in the soil to allow maximum evapotranspiration. In drier periods of the year, lack of water reduces actual evapotranspiration to an extent depending on the available soil moisture. Evapotranspiration in open water areas and wetlands is considered to be equal to be a fixed fraction of the reference evapotranspiration.

For each gridcell, runoff and ground water recharge is calculated as that part of the precipitation that does not evaporate and cannot be stored in the soil either. In other words, the sum of the runoff and ground water recharge is equal to the difference between precipitation and actual evaporation. Runoff is always positive except for areas identified as open water or wetland, where actual evapotranspiration can exceed precipitation.

Consumptive use of water in irrigated agriculture is defined as the water required in addition to water from precipitation (soil moisture) for optimal plant growth during the growing season. Optimal plant growth occurs when actual evapotranspiration of a crop is equal to its potential evapotranspiration.

Potential evapotranspiration of irrigated agriculture is calculated by converting data or projections of irrigated (sown) area by crop (at the national level) into a cropping calendar with monthly occupation rates of the land equipped for irrigation[1]. The table below gives as an example, the cropping calendar of Morocco for the base year 2005/07[2].

| Crop under irrigation | Irrigated area (1000 ha) | Crop area as share (percent) of the total area equipped for irrigation by month | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | J | F | M | A | M | J | J | A | S | O | N | D |
| Wheat | 618 | 46 | 46 | 46 | 46 | | | | | | 46 | 46 | 46 |
| Maize | 119 | | | 9 | 9 | 9 | 9 | 9 | | | | | |
| Potatoes | 61 | | | | | 5 | 5 | 5 | 5 | 5 | | | |
| Beet | 36 | | | | 3 | 3 | 3 | 3 | 3 | 3 | | | |
| Cane | 14 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Vegetables | 145 | | | | | 11 | 11 | 11 | 11 | 11 | | | |
| Citrus | 80 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| Fruits | 89 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| Groundnut | 6 | | | | | 1 | 1 | 1 | 1 | 1 | | | |
| Other crops | 124 | 9 | 9 | | | | | | | 9 | 9 | 9 | 9 |
| Sum over all crops[3] | 1292 | 69 | 69 | 69 | 72 | 42 | 42 | 42 | 32 | 41 | 69 | 69 | 69 |

1 India, China, Indonesia, the United States of America and the EU15 have been subdivided into two to four sub-regions for which different cropping calendars have been made to distinguish different climate zones in these countries.
2 E.g. wheat is grown from October through April and occupies 46 percent (618 thousand ha) of the 1292 thousand ha of irrigated land in use.
3 Including crops not shown above.

The (potential) evapotranspiration (ETc in mm) of a crop under irrigation is obtained by multiplying the reference evapotranspiration with a crop-specific coefficient (ETc = Kc * ET0). This coefficient has been derived (according to FAO, 1998) for four different growing stages: the initial phase (just after sowing), the development phase, the mid-phase and the late phase (when the crop is ripening to be harvested). In general, these coefficients are low during the initial phase, high during the mid-phase and again lower in the late phase. It is assumed that the initial, the development and the late phase, all take one month for each crop, while the mid-phase lasts a number of months. For example, the growing season for wheat in Morocco starts in October and ends in April, as follows: initial phase: October (Kc = 0.4), development phase: November (Kc = 0.8), mid-phase: December – March (Kc = 1.15), and late phase: April (Kc = 0.3).

Multiplying for each grid-cell its surface equipped for irrigation with the sum over all crops of their evapotranspiration and with the cropping intensity per month, results in the potential evapotranspiration of the irrigated area in that grid-cell. The difference between the calculated evapotranspiration of the irrigated area and actual evapotranspiration under non-irrigated conditions is equal to the consumptive use of water in irrigated agriculture in the grid-cell.

The method has been calibrated by comparing calculated values for water resources per country (i.e. the difference between precipitation and actual evapotranspiration under non-irrigated conditions) with data on water resources for each country as given in FAO AQUASTAT (www.fao.org/nr/aquastat). In addition, the discharge of major rivers as given in the literature was compared with the calculated runoff for the drainage basin of these rivers. If the calculated runoff values did not match the values as stated in the literature, correction factors were applied to one or more of the basic input data on soil moisture storage and open waters.

Finally, the water balance for each country and year is defined as the difference between the sum of precipitation and incoming run-off on the one hand and the sum of actual evapotranspiration and consumptive use of water in irrigated agriculture in that year on the other hand. This is therefore the balance of water without accounting for water withdrawals for other needs (industry, household and environmental purposes).

Nevertheless, for several countries, relatively low national figures may give an overly optimistic impression of the level of water stress: China, for instance, is facing severe water shortage in the north while the south still has abundant water resources. Already in 2005/07, four countries (Libya, Saudi Arabia, Yemen and Egypt) used volumes of water for irrigation larger than their annual renewable water resources. Groundwater mining also occurs in certain parts of some other countries of the Near East and in South and East Asia, Central America and in the Caribbean, even if at the national level the water balance may still be positive.

In concluding this section on irrigation, for the developing countries as a whole, water use in irrigation currently represents a relatively small part of their total water resources and there remains a significant potential for further irrigation development. With the relatively small increase in irrigation water withdrawal expected between 2005/07 and 2050, this situation will not change much at the aggregate level. Locally and in some countries, however, there are already very severe water shortages, in particular in the Near East/North Africa region.

### By how much do crop yields need to rise?

As discussed above, it is expected that growth in crop yields will continue to be the mainstay of crop production growth, accounting for some 70 percent of the latter in developing countries, and for all of it in the developed countries. Although the marked deceleration in crop production growth foreseen for the future (Table 2) could point to a similar deceleration in growth of crop yields, such growth will continue to be needed. Questions often asked are: will yield increases continue to be possible and what is the potential for a continuation of such growth? There is a realization that the chances of a new Green Revolution or of one-off quantum jumps in yields, are now rather limited. There is even a belief that for some major crops, yield ceilings have been, or are rapidly being, reached. At the same time, empirical evidence has shown that the cumulative gains in yields over time due to slower, evolutionary annual increments in yields, have been far more important than quantum jumps in yields, for all major crops (for example see Byerlee, 1996).

### Harvested land and yields for major crops

As mentioned before, the production projections for the 34 crops covered in this report are unfolded into and tested against what FAO experts think are “feasible” land-yield combinations by agro-ecological rainfed and irrigated environment, taking into account whatever knowledge is available. A major input into this evaluation are the estimates regarding the availability of land suitable for growing crops and of yields attainable in each country and each agro-ecological environment which originate in the Global Agro-Ecological Zones work (Fischer *et al*., 2002). In practice such estimates are introduced as constraints to land and yield expansion but they also act as a guide to what can be grown where. The resulting land and yield projections, although partly based on past performance, are not mere extrapolations of historical trends since they take into account present-day knowledge about changes expected in the future.

The overall result for yields of all the crops covered in this study (aggregated with standard price weights) is roughly a halving of the average annual rate of growth over the projection period as compared to the historical period: 0.8 percent p.a. during 2005/07 to 2050 against 1.7 percent p.a. during 1961-2007 (for the world. For the developing countries the annual growth rates are 0.9 and 2.1 percent respectively). This slowdown in the yield growth is a gradual process which has been under way for some time (for the last ten-year period 1997-07, the annual yield growth was 1.3 and 1.6 percent for the world and the group of developing countries respectively) and is expected to continue in the future. It reflects the deceleration in crop production growth explained earlier.

**Table 11. Area and yields for major crops in the world**

| | Production (million tonnes) | | | Harvested area (million ha) | | | Yield (tonnes/ha) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1961/63 | 2005/07 | 2050 | 1961/63 | 2005/07 | 2050 | 1961/63 | 2005/07 | 2050 |
| Wheat | 235 | 611 | 907 | 206 | 224 | 242 | 1.14 | 2.72 | 3.75 |
| Rice (paddy) | 227 | 641 | 784 | 117 | 158 | 150 | 1.93 | 4.05 | 5.23 |
| Maize | 210 | 733 | 1153 | 106 | 155 | 190 | 1.99 | 4.73 | 6.06 |
| Soybeans | 27 | 218 | 514 | 24 | 95 | 141 | 1.14 | 2.29 | 3.66 |
| Pulses | 41 | 60 | 88 | 69 | 71 | 66 | 0.59 | 0.84 | 1.33 |
| Barley | 84 | 138 | 189 | 59 | 57 | 58 | 1.43 | 2.43 | 3.24 |
| Sorghum | 44 | 61 | 111 | 48 | 44 | 47 | 0.93 | 1.39 | 2.36 |
| Millet | 25 | 32 | 48 | 43 | 36 | 34 | 0.58 | 0.86 | 1.43 |
| Seed cotton | 30 | 71 | 90 | 32 | 36 | 32 | 0.92 | 1.95 | 2.80 |
| Rape seed | 4 | 50 | 106 | 7 | 31 | 36 | 0.56 | 1.61 | 2.91 |
| Groundnuts | 15 | 36 | 74 | 17 | 24 | 39 | 0.86 | 1.49 | 1.91 |
| Sunflower | 7 | 30 | 55 | 7 | 23 | 32 | 1.00 | 1.29 | 1.72 |
| Sugarcane | 417 | 1413 | 3386 | 9 | 21 | 30 | 48.34 | 67.02 | 112.34 |

Note: crops selected and ordered according to (harvested) land use in 2005/07.

Discussing yield growth at this level of aggregation however is not very helpful, but the overall slowdown is a pattern common to most crops covered in this study with only a few exceptions such as citrus and sesame. These are crops for which a strong demand growth is foreseen in the future or which are grown in land-scarce environments. The growth in soybean area and production in developing countries (Table 11) has been remarkable mainly due to explosive growth in Brazil and Argentina. Soybean is expected to continue to be one of the most dynamic crops, albeit with its production increasing at a more moderate rate than in the past, bringing by 2050 the developing countries’ share in world soybean production to over 70 percent, with four countries (Brazil, Argentina, China and India) accounting for 90 percent of total production in developing countries.

For cereals, which occupy half (51 percent) of the harvested area in the world and in developing countries, the slowdown in yield growth would be particularly pronounced: at the world level down from 1.9 percent p.a. in the historical period to 0.7 percent p.a. over the projections period (from 2.2 to 0.8 percent p.a. in developing countries. Table 12). Again this slowdown has been underway for some time.

The differences in the sources of growth for the various regions have been discussed before. Suffice it here to note that irrigated land is expected to play a more important role in increasing maize production, almost entirely due to China which accounts for over 40 percent of the developing countries' maize production and where irrigated land allocated to maize could more than double. Part of the continued, albeit slowing, growth in yields is due to a rising share of irrigated production (with normally much higher cereal yields) in total production. This fact alone would lead to yield increases even if rainfed and irrigated cereal yields would not grow at all.

**Table 12: Cereal yields, rainfed and irrigated**

| | | World | | | | | | Developing countries | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Average yield | | | Annual growth | | | | | | Annual growth | | |
| | | tonnes/ha | | | % p.a. | | | | | | % p.a. | | |
| | | 1961/63 | 2005/07 | 2050 | 1961-07 | 1987-07 | 2005/07-2050 | 1961/63 | 2005/07 | 2050 | 1961-07 | 1987-07 | 2005/07-2050 |
| Wheat | total | 1.14 | 2.72 | 3.75 | 2.1 | 1.0 | 0.7 | 0.87 | 2.69 | 4.00 | 2.9 | 1.5 | 0.9 |
| | rainfed | | 2.37 | 3.17 | | | 0.7 | | 1.67 | 2.57 | | | 1.0 |
| | irrigated | | 3.50 | 5.08 | | | 0.8 | | 3.41 | 5.06 | | | 0.9 |
| Rice (paddy) | total | 1.93 | 4.05 | 5.23 | 1.8 | 1.1 | 0.6 | 1.82 | 3.98 | 5.18 | 1.9 | 1.1 | 0.6 |
| | rainfed | | 2.54 | 3.26 | | | 0.6 | | 2.54 | 3.26 | | | 0.6 |
| | irrigated | | 5.10 | 6.40 | | | 0.5 | | 5.04 | 6.37 | | | 0.5 |
| Maize | total | 1.99 | 4.72 | 6.06 | 2.0 | 1.9 | 0.6 | 1.16 | 3.22 | 4.56 | 2.5 | 2.1 | 0.8 |
| | rainfed | | 4.26 | 5.58 | | | 0.6 | | 2.70 | 3.69 | | | 0.7 |
| | irrigated | | 6.74 | 7.43 | | | 0.2 | | 5.27 | 6.53 | | | 0.5 |
| All cereals | total | 1.40 | 3.23 | 4.34 | 1.9 | 1.4 | 0.7 | 1.17 | 2.91 | 4.08 | 2.2 | 1.5 | 0.8 |
| | rainfed | | 2.64 | 3.58 | | | 0.7 | | 1.97 | 2.80 | | | 0.8 |
| | irrigated | | 4.67 | 6.10 | | | 0.6 | | 4.39 | 5.90 | | | 0.7 |

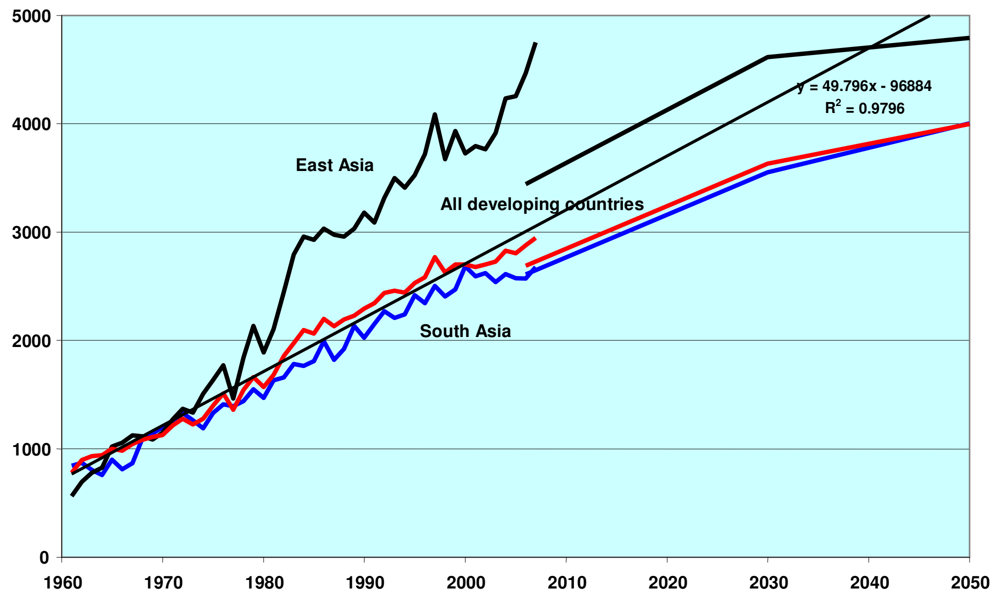
Note: Historical data are from FAOSTAT; base year data for China have been adjusted.

Increasing yields are often credited (see for example Borlaug, 1999) with saving land and thus diminishing pressure on the environment (e.g. less deforestation than otherwise would have taken place). To take cereals as an example, the reasoning is as follows. If the average global cereal yield had not grown since 1961/63 when it was 1405 kg/ha, 1620 million ha would have been needed to grow the 2276 million tonnes of cereals the world produced in 2005/07. This amount was actually obtained on an area of only 705 million ha at an average yield of 3230 kg/ha. Therefore, 915 million ha (1620 – 705) have been saved because of yield increases for cereals alone. This conclusion should be qualified however, since if there had been no yield growth, the most probable outcome would have been much lower production because of lower demand due to higher prices of cereals, and somewhat more land under cereals. Furthermore, in many countries the alternative of land expansion instead of yield increases, does not exist in practice.

### The scope for yield increases

Despite the increases in land under cultivation in the land-abundant countries, much of agricultural production growth has been based on the growth of yields, and will increasingly need to do so. What is the potential for a continuation of yield growth? In countries and localities where the potential of existing technology is being exploited fully, subject to the agro-ecological constraints specific to each locality, further growth, or even maintenance, of current yield levels will depend crucially on further progress in agricultural research. In places where yields are nearing ceilings obtained on research stations, the scope for raising yields is much more limited than in the past (Sinclair, 1998). Despite this, average yields have continued to increase, albeit at a decelerating rate. For example wheat yields in South Asia, which accounts for about a third of the developing countries' area under wheat, increased by 40 kg p.a. over 1961 to 2007 (27 kg p.a. over the last decade), and is projected to grow by 32 kg per year over the period 2005/07 to 2050. Similar increases for the group of developing countries are 50 kg (past. See Figure 9) and 30 kg (future) per annum.

**Figure 9: Wheat yields (kg/ha)**




Note: historical data from FAOSTAT. The break in the series for East Asia (and thus also for 'all developing countries') is due to a downward adjustment of the base year data for yields in China.

The variation in yields among countries however remains very wide. Table 13 illustrates this for wheat, rice and maize in developing countries. Current yields in the ten percent of countries with the lowest yields (bottom decile, excluding countries with less than 50 000 ha under the crop), are less than one-fifth (or 24 percent in the case of maize) of the yields of the best performers (top decile) and this 'gap' has been worsening over time. If sub-national data were available, probably a similar pattern would be seen for intra-national differences as well. For wheat and maize this gap between worst and best performers is projected to persist until 2050, while for rice the gap between the top and bottom deciles may be somewhat narrowed by 2050, with yields in the bottom decile reaching 25 percent of yields in the top decile. This may reflect the fact that the scope for raising yields of top rice performers is more limited than in the past. However, countries included in the bottom and top deciles account for only a minor share of the total production of wheat and rice. Therefore it is more important to examine what will happen to the yield levels obtained by the countries which account for the bulk of wheat, rice and maize production. Current (un-weighted) average yields of the largest producers[19] are about half the yields (40 percent in the case of maize) achieved by the top performers (Table 13). In spite of continuing yield growth in these largest producing countries, this situation is expected to remain essentially unchanged by 2050.

[19] Top ten percent of countries ranked according to area allocated to the crop examined. For 2005/07 these are China, India, and Turkey for wheat; India, China, Indonesia, Bangladesh and Thailand for rice; and China, Brazil, India, Mexico, Nigeria, Indonesia and United Republic of Tanzania for maize.

**Table 13: Average wheat, rice and maize yields in developing countries**

| | 1961/63 | | 2005/07 | | 2050 | |
|---|---|---|---|---|---|---|
| | tonnes /ha | as % of top decile | tonnes /ha | as % of top decile | tonnes /ha | as % of top decile |
| **Wheat** | | | | | | |
| Number of developing countries included | 31 | | 32 | | 33 | |
| Top decile | 2.15 | | 5.65 | | 9.02 | |
| Bottom decile | 0.40 | 18 | 0.83 | 15 | 1.50 | 17 |
| Decile of largest producers (by area) | 0.87 | 40 | 3.13 | 55 | 4.65 | 52 |
| All countries included | 0.98 | 46 | 2.35 | 42 | 3.77 | 42 |
| World | 1.48 | | 2.85 | | 3.60 | |
| **Rice (paddy)** | | | | | | |
| Number of developing countries included | 44 | | 53 | | 56 | |
| Top decile | 4.66 | | 7.52 | | 9.84 | |
| Bottom decile | 0.67 | 14 | 1.06 | 14 | 2.48 | 25 |
| Decile of largest producers (by area) | 1.84 | 39 | 4.16 | 55 | 5.19 | 53 |
| All countries included | 1.90 | 41 | 3.70 | 49 | 5.15 | 52 |
| World | 2.19 | | 3.74 | | 5.33 | |
| **Maize** | | | | | | |
| Number of developing countries included | 58 | | 69 | | 67 | |
| Top decile | 2.16 | | 7.77 | | 9.82 | |
| Bottom decile | 0.52 | 24 | 0.53 | 7 | 1.54 | 16 |
| Decile of largest producers (by area) | 1.21 | 56 | 3.15 | 41 | 4.92 | 50 |
| All countries included | 1.07 | 50 | 2.49 | 32 | 3.87 | 39 |
| World | 1.47 | | 3.77 | | 4.40 | |

Notes: (1) only countries with over 50 000 harvested ha are included; (2) countries included in the deciles are not necessarily the same for all years; (3) average yields are simple averages, not weighted by area.

Based on this analysis, a *prima facie* case could be made that there has been and still is considerable slack in the crop yields of the different countries, which could be exploited if the economic incentives so dictate. However, the fact that yield differences among the major cereal producing countries are very wide does not necessarily imply that the lagging countries have scope for yield increases equal to inter-country yield gaps. Part of these differences of course simply reflects differing agro-ecological conditions. However, not all, or perhaps not even the major part, of yield differences can be ascribed to such conditions as wide yield differences are present even among countries with fairly similar agro-ecological environments. In such cases, differences in the socio-economic and policy environments probably play a major role. The literature on yield gaps distinguishes two components of yield gaps, one due to agro-environmental and other non-transferable factors (these gaps cannot be narrowed), and another component due to differences in crop management practices such as sub-optimal use of inputs and other cultural practices. This second component can be narrowed provided that it makes economic sense to do so and therefore is termed the 'exploitable yield gap' or 'bridgeable gap'.

Duwayri *et al.* (1999) state that the theoretical maximum yields for both wheat and rice are probably in the order of 20 tonnes/ha. On experimental stations, yields of 17 tonnes/ha have been reached in subtropical climates and of 10 tonnes/ha in the tropics. FAO (1999) reports that concerted efforts in Australia to reduce the exploitable yield gap increased rice yields from 6.8 tonnes/ha in 1985/89 to 8.4 tonnes/ha in 1995/99, with many individual farmers obtaining 10 to 12 tonnes/ha.

In order to draw conclusions on the scope for narrowing the yield gap, one needs to separate its 'non-transferable' part from the 'exploitable' part. One way to do so is to compare yields obtained from the same crop varieties grown on different locations of land that are fairly homogeneous with respect to their physical characteristics (climate, soil, terrain) which would eliminate the 'non-transferable' part in the comparison. One can go some way in that direction by examining the data on the suitability of land in the different countries for producing any given crop under specified technology packages. The required data comes from the GAEZ analysis. These data make it possible to derive a 'national maximum obtainable yield' by weighting the yield obtainable in each of the suitability classes with the estimated land area in each suitability class. The derived national obtainable yield can then be compared with data on the actual national average yields. The findings presented below seem to confirm the hypothesis that a good part of the yield gap is of the second, exploitable type.

Countries with similar attainable averages for any given crop and technology level may be considered to be agro-ecologically similar for that crop. Naturally, any two countries can have similar attainable yields but for very different reasons, e.g. in some countries the limiting factors may be temperature and radiation, in others soil and terrain characteristics or moisture availability. Nevertheless, the GAEZ average attainable yields for any crop can be taken as a rough index of agro-ecological similarity of countries for producing that crop under the specified conditions.

Table 14 shows the agro-ecologically (AEZ) attainable national average wheat yields for sixteen countries[20] and compares them with actual prevailing yields[21]. These countries span a wide range of agro-ecological endowments for wheat production, with some countries having a high proportion of their "wheat land" in the Very Suitable category (e.g. France and Poland) and others having high proportions in the Suitable and Moderately Suitable categories (e.g. Kazakhstan and Canada). Attainable average yields in these countries range from over 7 tonnes/ha in Hungary, Romania, France and Ukraine to less then 4 tonnes/ha in Russia, Kazakhstan and Canada.

**Table 14: Agro-ecological suitability for rainfed wheat production, selected countries**

| | **Area suitable** | | | | **Yields attainable** | | | | **Actual average 2003/07** | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **total** | **VS#** | **S** | **MS** | **VS** | **S** | **MS** | **average** | **area** | **yield** |
| | **million ha** | | | | **tonnes /ha** | | | | **mln. ha** | **t/ha** |
| Romania | 14.4 | 8.3 | 4.2 | 1.9 | 9.0 | 6.9 | 5.2 | 7.9 | 2.0 | 2.6 |
| Hungary | 7.9 | 3.6 | 2.8 | 1.4 | 8.8 | 7.1 | 4.8 | 7.5 | 1.1 | 4.0 |
| France | 27.6 | 17.1 | 7.8 | 2.7 | 8.0 | 6.6 | 4.6 | 7.3 | 5.2 | 6.8 |
| Ukraine | 53.7 | 21.6 | 25.6 | 6.5 | 8.5 | 6.5 | 5.2 | 7.1 | 5.3 | 2.5 |
| Poland | 28.6 | 13.7 | 6.3 | 8.6 | 8.5 | 6.8 | 4.9 | 7.0 | 2.2 | 3.8 |
| Germany | 18.3 | 6.7 | 6.1 | 5.4 | 8.3 | 6.7 | 4.9 | 6.7 | 3.1 | 7.3 |
| Italy | 5.8 | 1.9 | 2.6 | 1.3 | 8.1 | 6.1 | 4.0 | 6.3 | 2.1 | 3.5 |
| United States of America | 357.8 | 124.9 | 132.2 | 100.7 | 8.4 | 6.0 | 4.1 | 6.3 | 20.3 | 2.8 |
| United Kingdom | 11.2 | 2.4 | 4.9 | 3.9 | 7.7 | 6.5 | 4.4 | 6.0 | 1.9 | 7.8 |
| Turkey | 24.8 | 2.5 | 9.4 | 13.0 | 6.6 | 5.8 | 4.7 | 5.3 | 8.9 | 2.2 |
| Denmark | 4.3 | 1.3 | 1.1 | 1.9 | 6.7 | 5.7 | 4.1 | 5.3 | 0.7 | 7.0 |
| Argentina | 87.6 | 8.3 | 36.0 | 43.3 | 6.6 | 5.2 | 3.7 | 4.6 | 5.6 | 2.6 |
| Australia | 47.4 | 3.7 | 15.5 | 28.2 | 6.7 | 5.2 | 3.6 | 4.4 | 12.7 | 1.5 |
| Russia | 406.1 | 91.9 | 168.0 | 146.2 | 5.9 | 3.9 | 2.4 | 3.8 | 23.0 | 1.9 |
| Kazakhstan | 20.6 | 0.2 | 3.3 | 17.0 | 5.7 | 4.9 | 2.9 | 3.3 | 11.9 | 1.1 |
| Canada | 158.9 | 12.8 | 43.0 | 103.2 | 5.8 | 3.3 | 2.2 | 2.8 | 9.5 | 2.5 |

# VS = Very Suitable, S = Suitable and MS = Moderately Suitable under high input. The data on potentials exclude marginally suitable land which in the GAEZ analysis is not considered appropriate for high input farming.
Source: Fischer *et al.* (2009, forthcoming) and FAOSTAT.

The divergence between economically efficient and agro-ecologically attainable yields can be very wide. For example, the United Kingdom and the United States of America have nearly equal attainable yields (6.0-6.3 tonnes/ha, but with the United States of America having much more land suitable for wheat growing than the United Kingdom) but actual yields are 7.8 tonnes/ha in the United Kingdom (in practice exceeding what the

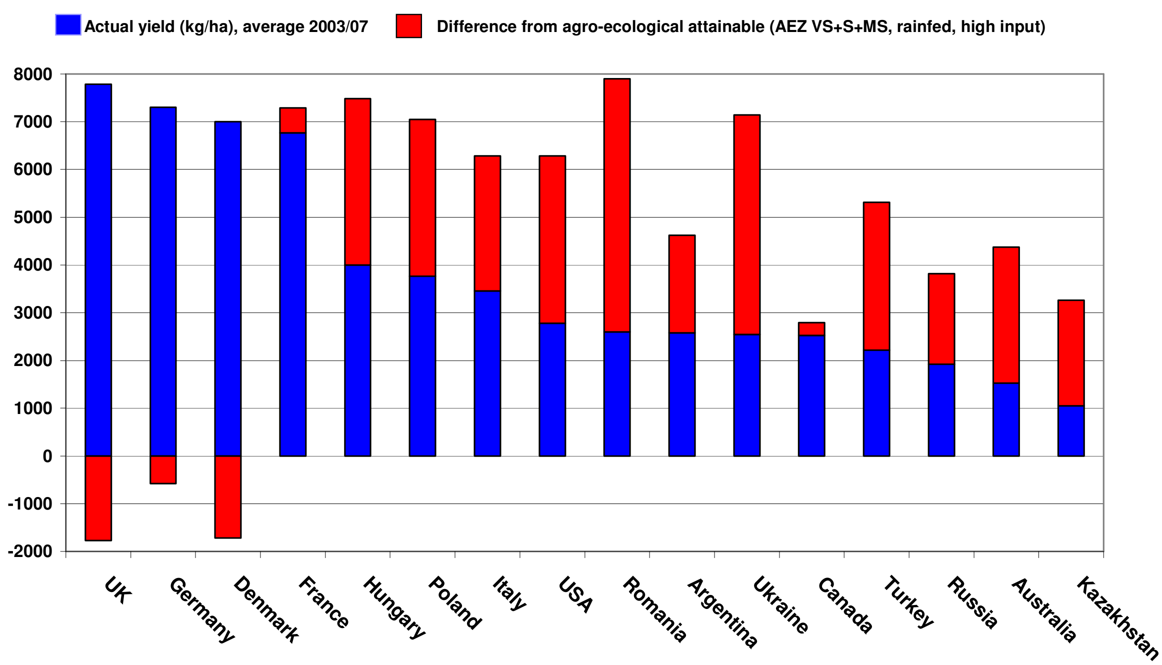
[20] 16 countries with more than 4 million tonnes of wheat production in 2003/07 and where rain-fed agriculture accounts for over 90 percent of total wheat production (except for Turkey: 80 percent).
[21] This comparison is somewhat distorted since the results of the GAEZ-2009 analysis (Fischer *et al*., forthcoming) available to us at the time of writing deals only with rainfed agriculture, while the national statistics include irrigated agriculture as well.

GAEZ evaluation suggests as attainable on the average) and 2.8 tonnes/ha in the United States of America. In spite of United States of America's yields being a fraction of those that are agro-ecologically attainable and of those prevailing in the United Kingdom, it is not necessarily a less efficient wheat producer than the UK in terms of production costs. Other examples of economically efficient wheat producers with low yields in relation to their agronomic potential include Argentina (2.6 tonnes/ha actual versus 4.6 tonnes/ha attainable) and the Ukraine (2.5 tonnes/ha versus 7.1 tonnes/ha).

The yield gap in relation to agronomic potential is an important element when discussing agronomic potentials for yield growth. For the countries in which we find large differences between actual and attainable, it seems probable that factors other than agro-ecology are responsible. Yields in these countries could grow some way towards bridging the gap between actual and attainable if some of these factors could be changed, e.g. if prices rose. We could then take the countries with a sizeable "bridgeable" gap, and see what is their aggregate weight in world production of a particular crop. If the weight is significant, then the world almost certainly has significant potential for increasing production through yield growth - even on the basis of existing knowledge and technology (varieties, farming practices, etc.).

Among the major wheat producers, only the EU countries (the United Kingdom, Denmark, France, Germany) have actual yields close to, or even higher than[22], those attainable for their agro-ecological endowments under rainfed high-input farming. In all other major producers with predominantly rainfed wheat production the gaps between actual and attainable yields are significant (Figure 10). Even assuming that only half of their yield gap (attainable minus actual) would be "bridgeable", their collective production could increase considerably without any increase in their area under wheat. As discussed above, yield growth would also occur in the other countries accounting for the rest of world production, including the major producers with irrigated wheat not included in Figure 10 such as China, India, Pakistan, Egypt. All this is without counting the potential yield gains that could come from further improvement in varieties - since the attainable yields of the GAEZ reflect the yield potential of existing varieties.

**Figure 10: Wheat: actual and agro-ecologically attainable yields**




[22] That actual yield levels in the United Kingdom, Germany and Denmark exceed the average S+VS+MS AEZ attainable yield can in part be explained if one assumes that all wheat is grown only on VS area (see Table 14).

Some States in India, such as the Punjab, are often quoted as examples of areas were wheat and rice yields have been slowing down or are even reaching a plateau. Fortunately, India is one of the few countries for which data at sub-national level and distinguished by rainfed and irrigated area are available. Bruinsma (2003, Table 11.2) compares wheat and rice yields by major growing State with the agro-ecologically attainable yields (as estimated in Fischer *et al.*, 2002), taking into account irrigation. It shows that, although yield growth has indeed been slowing down, in most cases actual yields are still far from the agro-ecologically attainable yields (with a few exceptions such as wheat in Haryana). This suggests that there are still considerable bridgeable yield gaps also in India.

The discussion above gives an idea of the scope for wheat production increases through the adoption of improved technologies and practices to bridge some of the gap that separates actual yields from obtainable yields. Wheat was used here as an example but similar analysis for other crops shows that the conclusions hold for all crops. The broad lesson of experience seems to be that if scarcities develop and prices rise, farmers quickly respond by adopting such technologies and increasing production, at least those living in an environment of not-too-difficult access to improved technology, transport infrastructure and supportive policies. However, in countries with land expansion possibilities, the quickest response comes from increasing land under cultivation, including shifting land among crops towards the most profitable ones.

Countries use only part of the land that is suitable for any given crop. This does not mean that land lies bare or fallow waiting to be used for increasing production of that particular crop. In most cases such land is also suitable for other crops and in practice is used for other crops. The point made here is that the gap existing between yields actually achieved and those obtainable under high input technology packages, affords significant scope for production increases through yield growth, given conducive socio-economic conditions, incentives and policies. The point is not that the production increases can be obtained by expanding cultivation into land suitable for a particular crop, because such land may not be available if it is used for other crops.

Moreover, even if there probably is sufficient slack in world agriculture to support further increases in global production, this is small consolation to food-insecure people who depend for their nutrition on what they themselves produce. Such people often live in semi-arid agricultural environments where the slack for increasing production can be very limited or non-existent. The fact that the world as a whole may have ample potential to produce more food is of little help to them.

The preceding discussion may create the impression that all is well from the standpoint of potential for further production growth based on the use of existing varieties and technologies to increase yields. This statement should however be heavily qualified since (i) exploitation of bridgeable yield gaps means further spread of high external input technologies, which might aggravate related environmental problems, and (ii) perhaps more important from the standpoint of meeting future demand, ready potential for yield growth does not necessarily exist in the countries where the additional demand will be. When the potential demand is in countries with limited import capacity, as is the case in many developing countries, such potential can be expressed as effective demand only if it can be predominantly matched by local production. In such circumstances, the existence of large exploitable yield gaps elsewhere (e.g. in Argentina or Ukraine) is less important than it appears for the evaluation of potential contributions of yield growth to meeting future demand.

It follows that continued and intensified efforts are needed on the part of the agricultural research community to raise yields (including through maintenance and adaptive research) in the often unfavourable agro-ecological and often also unfavourable socioeconomic environments of the countries where the additional demand will be.

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## APPENDIX: COUNTRIES AND CROPS INCLUDED IN THE ANALYSIS

### Countries covered

**Developing countries**

| Africa, sub-Saharan | Latin America and Caribbean | Near East/North Africa | South Asia |
|---|---|---|---|
| Angola | Argentina | Afghanistan | Bangladesh |
| Benin | Bolivia | Algeria | India |
| Botswana | Brazil | Egypt | Nepal |
| Burkina Faso | Chile | Iran, Islamic Rep. | Pakistan |
| Burundi | Colombia | Iraq | Sri Lanka |
| Cameroon | Costa Rica | Jordan | |
| Central Afr. Rep. | Cuba | Lebanon | |
| Chad | Dominican Rep. | Libyan Arab Yam. | |
| Congo | Ecuador | Morocco | |
| Côte d'Ivoire | El Salvador | Saudi Arabia | |
| Dem. Rep. of Congo | Guatemala | Syrian Arab Rep. | |
| Eritrea | Guyana | Tunisia | |
| Ethiopia | Haiti | Turkey | |
| Gabon | Honduras | Yemen | |
| Gambia | Jamaica | | |
| Ghana | Mexico | | |
| Guinea | Nicaragua | | ***East Asia*** |
| Kenya | Panama | | |
| Lesotho | Paraguay | | Cambodia |
| Liberia | Peru | | China |
| Madagascar | Suriname | | Dem. Rep. of Korea |
| Malawi | Trinidad and Tobago | | Indonesia |
| Mali | Uruguay | | Lao |
| Mauritania | Venezuela | | Malaysia |
| Mauritius | | | Myanmar |
| Mozambique | | | Philippines |
| Niger | | | Rep. of Korea |
| Nigeria | | | Thailand |
| Rwanda | | | Viet Nam |
| Senegal | | | |
| Sierra Leone | | | |
| Somalia | | | |
| Sudan | | | |
| Swaziland | | | |
| Togo | | | |
| Uganda | | | |
| United Rep. of Tanzania | | | |
| Zambia | | | |
| Zimbabwe | | | |

**Industrial countries**

| European Union-15 * | | Other Industrial Countries |
|---|---|---|
| Austria | Italy | Australia |
| Belgium | Luxembourg | Canada |
| Denmark | Netherlands | Iceland |
| Finland | Portugal | Israel |
| France | Spain | Japan |
| Germany | Sweden | New Zealand |
| Greece | United Kingdom | Norway |
| Ireland | | South Africa |
| | | Switzerland |
| | | United States of America |

## Transition countries

Russian Federation

| **Countries in the European Union*** | **Central Asia*** | **Other Eastern Europe*** |
|---|---|---|
| Czech Republic | Armenia | Albania |
| Estonia | Azerbaijan | Belarus |
| Hungary | Georgia | Bosnia and Herzegovina |
| Latvia | Kazakhstan | Bulgaria |
| Lithuania | Kyrgyzstan | Croatia |
| Malta | Tajikistan | Moldova Republic |
| Poland | Turkmenistan | Montenegro |
| Slovakia | Uzbekistan | Romania |
| Slovenia | | Serbia |
| | | The Former Yugoslav Rep. of Macedonia |
| | | Ukraine |

***** Country groups marked with an asterisk (*) were treated in the analysis as one aggregate

### Crops covered

| | |
|---|---|
| Wheat | Citrus fruit |
| Rice, paddy | Other fruit |
| Maize | Soy beans |
| Barley | Groundnuts |
| Millet | Sesame seed |
| Sorghum | Coconuts |
| Other cereals | Sunflower seed |
| Potatoes | Palm oil/palm-kernel oil |
| Sweet potatoes and yams | Rapeseed |
| Cassava | Other oilseeds |
| Other roots | Cocoa beans |
| Plantains | Coffee |
| Sugar beet | Tea |
| Sugar cane | Tobacco |
| Pulses | Seed cotton |
| Vegetables | Jute and hard fibres |
| Banana | Rubber |

# World Food and Agriculture to 2030/50:

How do climate change and bioenergy alter the long-term outlook
for food, agriculture and resource availability?

**Günther Fischer***

## 1. INTRODUCTION

Accumulating scientific evidence has alerted international and national awareness to the urgent need to mitigate climate change. Meanwhile, increasing and reoccurring extreme weather events devastate more and more harvests and livelihoods around the world.

Biofuels development has received increased attention in recent times as a means to mitigate climate change, alleviate global energy concerns and foster rural development. Its perceived importance in these three areas has seen biofuels feature prominently on the international agenda. Nevertheless, the rapid growth of biofuels production has raised many concerns among experts worldwide, in particular with regard to sustainability issues and the threat posed to food security (FAO, 2008a).

As recent events have shown, a number of factors including the adoption of mandatory biofuels policies, high crude oil prices, increasing global food import demand, below average harvests in some countries and low levels of world food stocks resulted in sudden and substantial increases in world food prices. The consequences were food riots around the world from Mexico to Haiti to Mauritania to Egypt to Bangladesh. Estimates indicate that high food prices increased the number of food insecure people by about 100 million.

This paper presents an integrated agro-ecological and socio-economic spatial global assessment of the inter-linkages of emerging biofuels developments, food security, and climate change. The explicit purpose is to quantify as to what extent climate change and expansion of biofuel production may alter the long-term outlook for food, agriculture and resource availability developed by the FAO in its Agriculture Toward 2030/50 assessment (Alexandratos, 2009; Bruinsma, 2009; FAO, 2006).

International Institute for Applied Systems Analysis' (IIASA)'s modeling framework and models have been developed to analyze spatially the world food and agriculture system and evaluate the impacts and implications of agricultural policies. The modeling framework has recently been extended and adapted to explicitly incorporate the issues of biofuel development. A brief summary of the methods and models applied in this study is presented below.

## 2. METHODOLOGY AND DATA

### The modeling framework

The analysis is based on a state-of-the-art ecological-economic modeling approach. The scenario-based quantified findings of the study rely on a modeling framework which includes as components, the FAO/IIASA Agro-ecological Zone model (AEZ) and the IIASA world food system model (WFS). The modeling framework encompasses climate scenarios, agro-ecological zoning information, demographic and socio-economic drivers,

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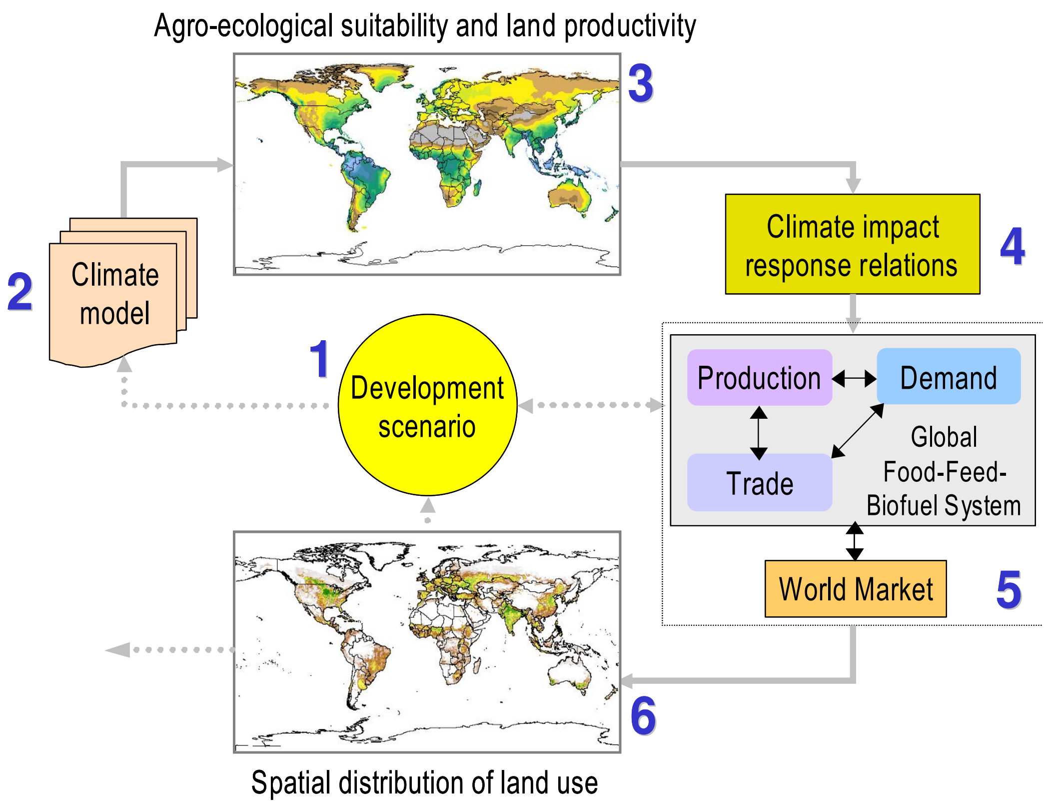
as well as production, consumption and world food trade dynamics (Fischer et al., 2009; Fischer et al., 2005). A summary description of the main model components is provided in Annex 1.

**Figure 2.1: Framework for ecological-economic world food system analysis**




This modeling framework comprises six main elements, as sketched in Figure 2.1:

1. A storyline and quantified development scenario (usually chosen from the extensive integrated assessment literature) is selected to inform the world food system model of demographic changes in each region and of projected economic growth in the non-agricultural sectors. It also provides assumptions characterizing in broad terms the international setting (e.g. trade liberalization; international migration) and the priorities regarding technological progress. It quantifies selected environmental variables, e.g. greenhouse gas emissions and atmospheric concentrations of $CO_2$. In this study it also defines scenarios of demand for first- and second-generation biofuels.
2. The emissions pathway associated with the chosen development scenario is used to select among available and matching published outputs of simulation experiments with general circulation models (GCMs). The climate change signals derived from the GCM results are combined with the observed reference climate to define future climate scenarios.
3. The agro-ecological zones method takes as input a climate scenario and estimates on a spatial grid of 5′ by 5′ latitude/longitude the likely agronomic impacts of climate change and identifies adaptation options.
4. Estimated spatial climate change impacts on yields for all crops are aggregated and incorporated into the parameterization of the national crop production modules of a regionalized world food system model.
5. The global general equilibrium world food system model is used – informed by the development storyline and estimated climate change yield impacts – to evaluate internally consistent world food system scenarios.

6. In a final step, the results of the world food system simulations are 'downscaled' to the spatial grid of the resource database for quantification of land cover changes and a further analysis of environmental implications of biofuels feedstock production.

The evaluation of the potential impacts on production, consumption and trade of agricultural commodities, caused by climate change and/or a rapid expansion of global biofuel use, was carried out in two steps. First, simulations were undertaken representing "futures" where biofuel production was abandoned or frozen at current levels (i.e. of year 2008) and kept constant for the remainder of the simulation period. Second, climate change impacts and alternative levels of biofuel demand, as derived from different energy scenarios, were simulated with the food system model and compared to the respective outcomes without additional biofuels demand or climate change.

The primary role of a reference scenario is to serve as "neutral" point of departure, from which various scenarios take off as variants, with the impact of climate change and/or biofuel expansion being seen in the deviation of these simulation runs from the outcomes of the reference scenario. The simulations were carried out on a yearly basis from 1990 to 2080.

## 3. BASELINE ASSESSMENT

Before turning to the impacts simulated for different assumptions on biofuel expansion and climate change, we briefly summarize results for a baseline projection. For this neutral point of departure, we have selected scenario FAO-REF-00 (see Table 7.1 in section 7), i.e. a reference projection of the system where no use of agricultural crops as feedstock for biofuel production is assumed and where current climate conditions prevail.

### Population increase and economic growth

In the long run, the increase of demand for agricultural products is largely driven by population and economic growth, both foremost in developing countries. Over the next two decades world population growth is projected at about one percent with most of the increase being in developing countries. Population increase is an exogenous input to the model analysis. The most recent available UN population projections (United Nations, 2009) where used as summarized in Table 3.1. Details of regional groupings in the world food system model are shown in Annex 2.

**Table 3.1: Population development**

| | Total population (millions) | | | | | |
|---|---|---|---|---|---|---|
| | **2000** | **2010** | **2020** | **2030** | **2040** | **2050** |
| North America | 306 | 337 | 367 | 392 | 413 | 430 |
| Europe & Russia | 752 | 762 | 766 | 761 | 748 | 729 |
| Pacific OECD | 150 | 153 | 152 | 148 | 142 | 135 |
| Africa, sub-Saharan | 655 | 842 | 1056 | 1281 | 1509 | 1723 |
| Latin America | 505 | 574 | 638 | 689 | 725 | 744 |
| Middle East & N. Africa | 303 | 370 | 442 | 511 | 575 | 629 |
| Asia, East | 1402 | 1500 | 1584 | 1633 | 1630 | 1596 |
| Asia, South/Southeast | 1765 | 2056 | 2328 | 2553 | 2723 | 2839 |
| Rest of World | 210 | 233 | 249 | 262 | 272 | 280 |
| Developed | 1141 | 1177 | 1202 | 1211 | 1210 | 1198 |
| Developing | 4696 | 5417 | 6132 | 6758 | 7257 | 7627 |
| Rest of World[1] | 210 | 233 | 249 | 262 | 272 | 280 |
| World | 6047 | 6827 | 7582 | 8231 | 8739 | 9105 |

Source: United Nations, March 2009.

[1] The regionalization used in the world food system model is described in Annex 2.

Economic performance in the baseline projection FAO-REF-00 is shown in Table 3.2. For the analysis reported here the economic growth characteristics were calibrated by country or regional group to match basic assumptions of the FAO perspective study Agriculture Toward 2030/50 based on information provided by the Agriculture Toward 2030/50 study group at FAO (J. Bruinsma, May 2009; personal communication).

**Table 3.2: GDP at constant 1990 prices**

| FAO-REF-01 | GDP (billion US $ at constant 1990 prices) | | | | | |
|---|---|---|---|---|---|---|
| | **2000** | **2010** | **2020** | **2030** | **2040** | **2050** |
| North America | 8286 | 10582 | 12427 | 13817 | 15480 | 17050 |
| Europe & Russia | 7502 | 9487 | 11621 | 14037 | 16860 | 19832 |
| Pacific OECD | 3795 | 4304 | 4781 | 5173 | 5534 | 5888 |
| Africa, sub-Saharan | 238 | 350 | 531 | 808 | 1236 | 1894 |
| Latin America | 1450 | 2014 | 2822 | 4267 | 6284 | 8828 |
| Middle East & N. Africa | 597 | 850 | 1212 | 1772 | 2623 | 3845 |
| Asia, East | 1596 | 4165 | 8037 | 13106 | 18373 | 24625 |
| Asia, South/Southeast | 1255 | 2020 | 3136 | 4840 | 7293 | 10139 |
| Rest of World | 2418 | 3000 | 3640 | 4343 | 5103 | 5913 |
| Developed | 19583 | 24372 | 28830 | 33028 | 37875 | 42770 |
| Developing | 5135 | 9399 | 15738 | 24795 | 35810 | 49331 |
| Rest of World | 2418 | 3000 | 3640 | 4343 | 5103 | 5913 |
| World | 27136 | 36771 | 48207 | 62165 | 78788 | 98014 |

Source: IIASA world food system simulations; scenario FAO-REF-00, May 2009.

While the recent economic growth rates of more than 8 percent annually in China and India may have been dented by the recent world financial crisis, relatively robust economic growth in China, India and other middle-income developing countries is expected in the next two decades.

### Agricultural demand and production

Crop production is driven by yield and acreage developments. In many developing countries the crop yields for most commodities are lower than those attained in developed countries. At the global level grain yields increased by an average of some 2 percent annually in the period 1970 to 1990 but since then the rate of yield growth has halved.

**Table 3.3: Total cereal production and consumption; Baseline simulation without considering climate change and biofuel expansion**

| FAO-REF-00 | Cereal production (million tons) | | | | Cereal consumption (million tons) | | | |
|---|---|---|---|---|---|---|---|---|
| | **2000** | **2020** | **2030** | **2050** | **2000** | **2020** | **2030** | **2050** |
| North America | 474 | 588 | 645 | 707 | 304 | 354 | 376 | 404 |
| Europe & Russia | 526 | 552 | 575 | 650 | 545 | 590 | 621 | 684 |
| Pacific OECD | 40 | 48 | 49 | 55 | 46 | 50 | 52 | 52 |
| Africa, sub-Saharan | 76 | 133 | 172 | 265 | 106 | 179 | 233 | 347 |
| Latin America | 130 | 197 | 221 | 269 | 139 | 196 | 227 | 272 |
| Middle East & N. Africa | 55 | 82 | 94 | 122 | 99 | 148 | 179 | 234 |
| Asia, East | 423 | 525 | 568 | 636 | 461 | 570 | 620 | 677 |
| Asia, South/Southeast | 345 | 450 | 496 | 573 | 341 | 453 | 494 | 573 |
| Rest of World | 75 | 94 | 103 | 125 | 103 | 120 | 128 | 146 |
| Developed | 1008 | 1149 | 1229 | 1363 | 858 | 945 | 993 | 1072 |
| Developing | 1060 | 1425 | 1590 | 1914 | 1183 | 1596 | 1808 | 2171 |
| Rest of World | 75 | 94 | 103 | 125 | 103 | 120 | 128 | 146 |
| World | 2143 | 2668 | 2923 | 3402 | 2144 | 2661 | 2928 | 3388 |

Source: IIASA world food system simulations; scenario FAO-REF-00, May 2009.

With still considerable population growth in the reference projections of scenario FAO-REF-00, total production of cereals increases from 2.1 billion tons in 2000 to 2.9 billion tons in 2030, and further to 3.4 billion tons in 2050. While developing countries produced about half the global cereal harvest in 2000, their share in total production increases steadily, reaching 57 percent by 2050. As their share in global consumption increases from 55 percent to 64 percent in this reference projection, net imports of cereals by developing countries are growing over time, from 120 million tons in 2000 to about 220 million tons in 2030, and some 250 million tons by 2050.

## Agricultural prices

Real prices of agricultural crops declined by a factor of more than two during the period from the late 1970s to the early 1990s and then stagnated until about 2002 when food prices started to rise. The long term trend in declining food prices has been the result of several drivers: population development and slowing demographic growth; technological development and growing input use in agriculture, notably substantial increase in productivity since the green revolution in the early 1970s; and support policies maintaining relatively inelastic agricultural supply in developed countries.

The index of world food prices has increased by some 140 percent during the period 2002 to 2007 primarily a result of increased demand for cereals and oilseeds for biofuels, low world food stocks, reduced harvest in some locations, for example in Australia and Europe due to drought conditions, record oil and fertilizer prices and world market speculation. Since the second half of 2008 agricultural prices have again been decreasing substantially.

The baseline projection of scenario FAO-REF-00 is characterized by modest increases of world market prices during 2000 to 2050. Table 3.4 shows projected price indexes for crops and livestock products in comparison to 1990 levels for a reference simulation without considering climate change or expansion of biofuel production. In part, this is also the outcome of an assumed further reduction of agricultural support and protection measures.[2]

**Table 3.4: Agricultural prices in the Baseline projection, scenario FAO-REF-00**

| | Price Index (1990=100) | | | |
|---|---|---|---|---|
| Commodity group | 2020 | 2030 | 2040 | 2050 |
| Crops | 94 | 99 | 107 | 113 |
| Cereals | 104 | 106 | 114 | 123 |
| Other crops | 90 | 95 | 103 | 108 |
| Livestock products | 107 | 110 | 115 | 119 |
| Agriculture | 98 | 102 | 109 | 115 |

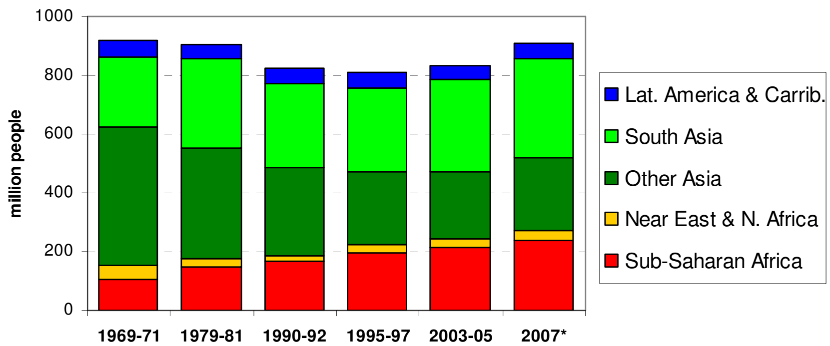
Source: IIASA world food system simulations; scenario FAO-REF-00, May 2009.

## Risk of hunger

In 1970, 940 million people in developing countries, a third of the population, were regarded as chronically undernourished. During the next two decades, the number of undernourished people declined by some 120 million to estimated 815 million in 1990. The largest reduction occurred in East Asia where the number of undernourished people declined from some 500 million in 1970 to about 250 million in 1990. The number of undernourished people increased slightly in South Asia and almost doubled in sub-Saharan Africa. The total number of undernourished in the developing countries further declined from 815 million in 1990 to 776 million people in 2000. During this same period, the number of undernourished in sub-Saharan Africa increased from 168 million to 194 million. Africa has the highest proportion of undernourished people, about 35 percent of the total population compared to about 14 percent of the total population of the rest of the developing world.

[2] Price dynamics critically depend on assumed long-term rates of technological progress in agriculture. Therefore, the price trends presented here should not be interpreted as a 'prediction' of future price development but is rather shown as a characteristic of the chosen reference simulation.

**Figure 3.5: Historical trends in number of undernourished people, developing countries**




Source: FAO (2008b; 2001).
Note: FAO states the estimate for 2007 is based on partial data for 2006-08 and a simplified methodology and should therefore be regarded as provisional.

The FAO-REF-00 scenario projects a globally decreasing number of people at risk of hunger. The projected decrease is most pronounced in East Asia and South Asia. For Africa a further increase in the number of people at risk of hunger is projected, resulting for 2020 in 35 percent of the total number of people at risk of hunger to originate from Africa, and 40 percent in 2030. While achieving some progress in mitigating hunger, the projected development in this reference scenario FAO-REF-00 is far from being sufficient to meet the reductions necessary to achieve the Millennium Development Goal.

**Table 3.5: People at risk of hunger, Baseline projection FAO-REF-00**

| FAO-REF-01 | Millions | | | | | |
|---|---|---|---|---|---|---|
| | **2000** | **2010** | **2020** | **2030** | **2040** | **2050** |
| Africa, sub-Saharan | 196 | 252 | 286 | 271 | 258 | 239 |
| Latin America | 56 | 43 | 31 | 20 | 14 | 10 |
| Middle East & N. Africa | 42 | 51 | 57 | 53 | 52 | 47 |
| Asia, East | 173 | 139 | 104 | 68 | 42 | 26 |
| Asia, South/Southeast | 364 | 378 | 362 | 278 | 192 | 136 |
| Developing countries | 833 | 864 | 839 | 691 | 557 | 458 |

Source: IIASA world food system simulations; scenario FAO-REF-00, May 2009.

### Value added of crop and livestock production

In the FAO-REF-00 scenario, the global value added of crop and livestock production in 2000 amounts to US1990$ 1260 billion. This is projected to increase by 30 percent in the 20-year period to 2020. In 2030 and 2050 the projected value added amounts to respectively US1990$ 1836 and US1990$ 2192 billion.

**Table 3.6: Value added of crop and livestock sector (billion US$ 1990)**

| FAO-REF-00 | Billion US$ 1990 | | | | | |
|---|---|---|---|---|---|---|
| | **2000** | **2010** | **2020** | **2030** | **2040** | **2050** |
| North America | 166 | 179 | 192 | 203 | 214 | 226 |
| Europe & Russia | 206 | 220 | 235 | 245 | 255 | 264 |
| Pacific OECD | 47 | 52 | 57 | 62 | 67 | 71 |
| Africa, sub-Saharan | 65 | 82 | 105 | 133 | 165 | 198 |
| Latin America | 155 | 190 | 227 | 262 | 289 | 308 |
| Middle East & N. Africa | 55 | 70 | 86 | 104 | 122 | 141 |
| Asia, East | 249 | 282 | 314 | 342 | 365 | 384 |
| Asia, South/Southeast | 252 | 299 | 348 | 400 | 450 | 498 |
| Rest of World | 65 | 71 | 78 | 85 | 93 | 101 |
| Developed | 419 | 451 | 483 | 510 | 535 | 561 |
| Developing | 775 | 923 | 1081 | 1241 | 1391 | 1530 |
| Rest of World | 65 | 71 | 78 | 85 | 93 | 101 |
| World | 1259 | 1445 | 1642 | 1836 | 2019 | 2192 |

Source: IIASA world food system simulations; scenario FAO-REF-00, May 2009.

### Cultivated land

Some 1.6 billion ha of land are currently used for crop production, with nearly 1 billion ha under cultivation in the developing countries. During the last 30 years the world's crop area expanded by some 5 million ha annually, with Latin America alone accounting for 35 percent of this increase. The potential for arable land expansion exists predominantly in South America and Africa where just seven countries account for 70 percent of this potential. There is relatively little scope for arable land expansion in Asia, which is home to some 60 percent of the world's population.

Projected global use of cultivated land in the FAO-REF-00 baseline scenario increases by about 165 million ha during 2000 to 2050. While aggregate arable land use in developed countries remains fairly stable, practically all of the net increases occur in developing countries. Africa and South America together account for 85 percent of the expansion of cultivated land (Table 3.7).

**Table 3.7: Cultivated land (million hectares)**

| FAO-REF-00 | Million hectares | | | | | |
|---|---|---|---|---|---|---|
| | **2000** | **2010** | **2020** | **2030** | **2040** | **2050** |
| North America | 234 | 235 | 236 | 237 | 241 | 244 |
| Europe & Russia | 339 | 337 | 336 | 334 | 334 | 334 |
| Pacific OECD | 57 | 57 | 57 | 57 | 60 | 61 |
| Africa, sub-Saharan | 226 | 245 | 265 | 284 | 301 | 315 |
| Latin America | 175 | 193 | 208 | 217 | 223 | 224 |
| Middle East & N. Africa | 67 | 69 | 70 | 72 | 73 | 74 |
| Asia, East | 147 | 146 | 146 | 146 | 145 | 145 |
| Asia, South/Southeast | 274 | 281 | 286 | 289 | 292 | 293 |
| Rest of World | 42 | 41 | 40 | 38 | 38 | 37 |
| Developed | 604 | 602 | 601 | 602 | 606 | 610 |
| Developing | 915 | 960 | 1002 | 1035 | 1063 | 1081 |
| Rest of World | 42 | 41 | 40 | 38 | 38 | 37 |
| World | 1561 | 1603 | 1643 | 1676 | 1707 | 1727 |

Source: IIASA world food system simulations; scenario FAO-REF-00, May 2009.

Cultivated land represents the physical amount of land used for crop production. In practice, part of the land is left idle or fallow, and part of the cultivated land is used to produce multiple crops within one year. The total harvested area in scenario FAO-REF-00 is shown in Table 3.8. The implied cropping intensity in the baseline projection increases from about 84 percent in 2000 to 89 percent in 2030, and to 92 percent in 2050.

**Table 3.8: Harvested area (million hectares)**

| FAO-REF-00 | Million hectares | | | | | |
|---|---|---|---|---|---|---|
| | **2000** | **2010** | **2020** | **2030** | **2040** | **2050** |
| North America | 196 | 203 | 210 | 215 | 223 | 231 |
| Europe & Russia | 215 | 216 | 218 | 219 | 221 | 223 |
| Pacific OECD | 25 | 26 | 27 | 28 | 30 | 31 |
| Africa, sub-Saharan | 134 | 152 | 174 | 194 | 214 | 231 |
| Latin America | 126 | 143 | 160 | 171 | 179 | 180 |
| Middle East & N. Africa | 42 | 46 | 50 | 53 | 56 | 59 |
| Asia, East | 220 | 224 | 228 | 231 | 233 | 234 |
| Asia, South/Southeast | 312 | 327 | 341 | 350 | 356 | 359 |
| Rest of World | 35 | 35 | 35 | 35 | 35 | 35 |
| Developed | 421 | 429 | 438 | 446 | 457 | 468 |
| Developing | 850 | 909 | 968 | 1016 | 1055 | 1080 |
| Rest of World | 35 | 35 | 35 | 35 | 35 | 35 |
| World | 1306 | 1373 | 1441 | 1497 | 1547 | 1583 |

Source: IIASA world food system simulations; scenario FAO-REF-00, May 2009.

## 4. CLIMATE CHANGE IMPACTS ON CROP SUITABILITY AND PRODUCTION POTENTIAL

Climate change and variability affect thermal and hydrological regimes, and in turn, this influences the structure and functionality of ecosystems and human livelihoods.

Scenarios of climate change were developed in order to estimate their effects on crop yields, extents of land with cultivation potential, and the number and type of crop combinations that can be cultivated. A climate change scenario is defined as a physically consistent set of changes in meteorological variables, based on generally accepted projections of $CO_2$ (and other trace gases) levels.

For the spatial assessment of agronomic impacts of climate change on crop yields with the AEZ family of crop models, climate change parameters are computed at each grid point of the resource inventory by comparing GCM monthly-mean prediction for the given decade to those corresponding to the GCM "baseline" climate of 1960-1990. Such changes (i.e. differences for temperature; ratios for precipitation, etc.) are then applied to the observed climate of 1960-1990, used in AEZ, to generate future climate data – a plausible range of outcomes in terms of likely future temperatures, rainfall, incoming sun light, etc. for the nominal years 2025 (termed the 2020s), 2055 (i.e. the 2050s) and 2085 (termed the 2080s).

**Table 4.1: Impacts of climate change on production potential of rain-fed wheat of current cultivated land (percent changes with respect to potential under current climate)**

| Region | Cultivated Land | Hadley A2, 2050s versus Reference Climate | | | |
|---|---|---|---|---|---|
| | | Without $CO_2$ fertilization; current crop types | Without $CO_2$ fertilization; adapted crop types | With $CO_2$ fertilization; current crop types | With $CO_2$ fertilization; adapted crop types |
| North America | 230 | -9 | -9 | -3 | -3 |
| Europe | 179 | -4 | -4 | 3 | 3 |
| Russian Fed. | 126 | -1 | -1 | 5 | 5 |
| Central America & Carrib. | 43 | -48 | -57 | -45 | -54 |
| South America | 129 | -24 | -26 | -20 | -22 |
| Oceania & Polynesia | 53 | 11 | 12 | 16 | 18 |
| North Africa & West Asia | 59 | -8 | -7 | -2 | -1 |
| North Africa | 19 | -16 | -14 | -11 | -9 |
| West Asia | 40 | -4 | -4 | 2 | 2 |
| Sub-Saharan Africa | 225 | -56 | -61 | -54 | -59 |
| Eastern Africa | 83 | -59 | -65 | -57 | -63 |
| Middle Africa | 38 | -76 | -80 | -75 | -80 |
| Southern Africa | 17 | -44 | -47 | -41 | -44 |
| Western Africa | 86 | -98 | -99 | -98 | -98 |
| Asia | 519 | -16 | -17 | -11 | -13 |
| Southeast Asia | 98 | -55 | -58 | -53 | -56 |
| South Asia | 229 | -40 | -43 | -37 | -40 |
| East Asia & Japan | 151 | -8 | -9 | -3 | -5 |
| Central Asia | 41 | 15 | 15 | 21 | 21 |
| Developed | 591 | -5 | -5 | 1 | 2 |
| Developing | 972 | -22 | -24 | -18 | -20 |
| World | 1563 | -10 | -11 | -5 | -5 |

Source: GAEZ 2009 simulations; May 2009.

The range of results computed in AEZ refers to different assumptions concerning autonomous adaptation in cropping and effects of CO2 fertilization on crop yields (e.g. see different columns in Table 4.1). The first variant is quantified without considering the effects of CO2 fertilization and assumes that farmer's would be able to change cropping dates and crop types but would be limited to local crop varieties, i.e. crop varieties with temperature characteristics and moisture requirements of LUT's used in current climate. The second column refers to results where CO2 fertilization is still not considered but best adapted plant types, e.g. available elsewhere and adapted to higher temperatures, would be available to maximize production potential. Variants 3 and 4 take into account effects of CO2 fertilization and quantify outcomes respectively with limited and full adaptation of crop types.

The results for wheat presented in Table 4.1 are based on a spatial climate change scenario derived from outputs of the UK HadCM3 model (Gordon et al., 2000; Pope et al.; 2000) for the IPCC SRES A2 emissions pathway (Nakicenovic et al., 2000).

Except for countries in Central Asia, the impact of climate change on wheat production in developing countries is generally negative. In contrast, rain-fed wheat production potential of current cultivated land in Europe, Russia and Oceania is increasing. The net global balance is projected to be a reduction of production potential by 2050s of five to ten percent.

**Table 4.2: Impacts of climate change on production potential of rain-fed maize of current cultivated land (% changes with respect to potential under current climate)**

| Region | Cultivated Land | Hadley A2, 2050s versus Reference Climate | | | |
|---|---|---|---|---|---|
| | | Without $CO_2$ fertilization; current crop types | Without $CO_2$ fertilization; adapted crop types | With $CO_2$ fertilization; current crop types | With $CO_2$ fertilization; adapted crop types |
| North America | 230 | -5 | -1 | -2 | 2 |
| Europe | 179 | 23 | 23 | 28 | 27 |
| Russian Fed. | 126 | 61 | 61 | 66 | 67 |
| Central America & Carrib. | 43 | 1 | 5 | 5 | 9 |
| South America | 129 | -3 | 2 | 0 | 6 |
| Oceania & Polynesia | 53 | 27 | 30 | 31 | 34 |
| North Africa & West Asia | 59 | 31 | 30 | 34 | 34 |
| North Africa | 19 | 51 | 52 | 55 | 56 |
| West Asia | 40 | 23 | 22 | 26 | 25 |
| Sub-Saharan Africa | 225 | -6 | -3 | -3 | 1 |
| Eastern Africa | 83 | 1 | 5 | 5 | 9 |
| Middle Africa | 38 | -4 | 1 | -1 | 5 |
| Southern Africa | 17 | -45 | -44 | -43 | -43 |
| Western Africa | 86 | -8 | -5 | -5 | -1 |
| Asia | 519 | -2 | 2 | 2 | 6 |
| Southeast Asia | 98 | 2 | 6 | 5 | 9 |
| South Asia | 229 | -7 | -3 | -3 | 1 |
| East Asia & Japan | 151 | 3 | 7 | 7 | 11 |
| Central Asia | 41 | 23 | 26 | 26 | 30 |
| Developed | 591 | 13 | 15 | 17 | 19 |
| Developing | 972 | -3 | 1 | 1 | 5 |
| World | 1563 | 2 | 5 | 6 | 9 |

Source: GAEZ 2009 simulations; May 2009.

Table 4.2 summarizes the simulated AEZ results for rain-fed grain maize. The global production potential of current cultivated land under projected HadCM3 climate conditions of the 2050s increases in all four variants owing to a modest increase (or only slight aggregated decrease) of the grain maize potential in developing countries and a significant improvement in developed regions. Despite this improvement at global level, there are also several regions where maize production potential decreases, including in Sub-Saharan Africa.

**Table 4.3: Impacts of climate change on the production potential of rain-fed cereals in current cultivated land (percent changes with respect to potential under current climate)**

| Region | Cultivated Land | Hadley A2, 2050s versus Reference Climate | | | |
|---|---|---|---|---|---|
| | | Without $CO_2$ fertilization; current crop types | Without $CO_2$ fertilization; adapted crop types | With $CO_2$ fertilization; current crop types | With $CO_2$ fertilization; adapted crop types |
| North America | 230 | -7 | -6 | -1 | 0 |
| Europe | 179 | -4 | -4 | 3 | 3 |
| Russian Fed. | 126 | 3 | 3 | 9 | 9 |
| Central America & Carrib. | 43 | -10 | -6 | -6 | -2 |
| South America | 129 | -8 | -3 | -4 | 1 |
| Oceania & Polynesia | 53 | 2 | 4 | 6 | 8 |
| North Africa & West Asia | 59 | -8 | -7 | -2 | -1 |
| North Africa | 19 | -15 | -13 | -10 | -8 |
| West Asia | 40 | -4 | -4 | 1 | 1 |
| Sub-Saharan Africa | 225 | -7 | -3 | -3 | 1 |
| Eastern Africa | 83 | -3 | 2 | 2 | 6 |
| Middle Africa | 38 | -7 | -2 | -3 | 3 |
| Southern Africa | 17 | -32 | -31 | -29 | -28 |
| Western Africa | 86 | -7 | -4 | -3 | 1 |
| Asia | 519 | -3 | 1 | 2 | 5 |
| Southeast Asia | 98 | -5 | -1 | -1 | 4 |
| South Asia | 229 | -6 | -2 | -2 | 2 |
| East Asia & Japan | 151 | 2 | 6 | 7 | 10 |
| Central Asia | 41 | 14 | 14 | 19 | 19 |
| Developed | 591 | -3 | -3 | 2 | 3 |
| Developing | 972 | -5 | -2 | -1 | 3 |
| World | 1563 | -5 | -2 | 0 | 3 |

Source: GAEZ 2009 simulations; May 2009.

Results compiled in Table 4.3 go beyond climate change impacts for single crops. The computations look at all cereal types represented in AEZ (some 118 LUTs covering wheat, rice, maize, barley, sorghum, millet, rye, oats and buckwheat) and determine separately for current climate and for future climate conditions the most productive cereal type in each grid-cell of the spatial resource inventory. Results indicate a somewhat increasing global rain-fed production potential, provided $CO_2$ fertilization is effective and full adaptation of crop types is achieved; but climate change could as well result in a reduction of the global production of about 5 percent if these two aspects were not achieved. In the latter case most regions would experience a reduction. At the regional level, results for Southern Africa, North Africa and Central America show the largest negative climate change impacts on rain-fed cereal production potential.

Table 4.4 presents results for the temporal dimension of climate change impacts by summarizing simulated results based on HadCM3 for three periods, the 2020s, the 2050s and the 2080s. Numbers shown in the table are ‘best’ outcomes of the four variants discussed above, i.e. assuming effective $CO_2$ fertilization and full agronomic crop adaptation.

Results suggest that for the next decades the global rain-fed cereal production potential is not threatened by a gradual change of climate as projected by the HadCM3 model for the IPCC SRES A2 emissions scenario provided $CO_2$ fertilization effects materialize and farmers are prepared and empowered to fully adapt to a changing climate. It should also be noted that the results in Table 4.4 do not account for impacts of possibly increased climatic variability.

**Table 4.4: Impacts of climate change on the production potential of rain-fed cereals in current cultivated land (% change with respect to current climate)**

| Region | Hadley A2 versus Reference Climate (% change; with $CO_2$ fertilization) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Rain-fed Wheat | | | Rain-fed Maize | | | Rain-fed Cereals | | |
| | 2020s | 2050s | 2080s | 2020s | 2050s | 2080s | 2020s | 2050s | 2080s |
| North America | -1 | -3 | -2 | 7 | 2 | -1 | 1 | 0 | 0 |
| Europe | 1 | 3 | -1 | 22 | 27 | 21 | 1 | 3 | -1 |
| Russian Fed. | 3 | 5 | -1 | 54 | 67 | 63 | 5 | 9 | 6 |
| Central America | -33 | -54 | -76 | 6 | 9 | -1 | -1 | -2 | -15 |
| South America | -14 | -22 | -33 | 2 | 6 | 5 | 1 | 1 | -1 |
| Oceania & Polynesia | -8 | 18 | 9 | 12 | 34 | 58 | -7 | 8 | 2 |
| North Afr & West Asia | 2 | -1 | -12 | 19 | 34 | 39 | 2 | -1 | -11 |
| North Africa | 2 | -9 | -28 | 38 | 56 | 60 | 2 | -8 | -23 |
| West Asia | 2 | 2 | -6 | 12 | 25 | 31 | 2 | 1 | -5 |
| Sub-Saharan Africa | -36 | -59 | -76 | 1 | 1 | 1 | 1 | 1 | 0 |
| Eastern Africa | -38 | -63 | -81 | 6 | 9 | 11 | 3 | 6 | 9 |
| Middle Africa | -53 | -80 | -95 | 5 | 5 | 5 | 2 | 3 | 2 |
| Southern Africa | -27 | -44 | -61 | -29 | -43 | -32 | -20 | -28 | -24 |
| Western Africa | -77 | -98 | -100 | 1 | -1 | -6 | 1 | 1 | -5 |
| Asia | -7 | -13 | -31 | 2 | 6 | 4 | 3 | 5 | 3 |
| Southeast Asia | -27 | -56 | -89 | 4 | 9 | 11 | 2 | 4 | -1 |
| South Asia | -10 | -40 | -71 | 1 | 1 | -2 | 2 | 2 | -1 |
| East Asia & Japan | -9 | -5 | -16 | 1 | 11 | 12 | 1 | 10 | 12 |
| Central Asia | 10 | 21 | 9 | 25 | 30 | 16 | 16 | 19 | 11 |
| Developed | 0 | 2 | -1 | 18 | 19 | 16 | 2 | 3 | 1 |
| Developing | -11 | -20 | -36 | 2 | 5 | 3 | 2 | 3 | 0 |
| World | -3 | -5 | -12 | 7 | 9 | 7 | 2 | 3 | 0 |

Source: GAEZ 2009 simulations; May 2009.

Table 4.5 presents results for AEZ estimated rain-fed crop potentials of wheat, maize and sorghum (relative to reference climate) based on the CSIRO GCM climate projections for IPCC A2 emissions pathways. Estimates assume full adaptation of crop types and include effects of CO2 fertilization due to increased atmospheric CO2 concentrations. Table 4.6 summarizes changes relative to crop potentials of current climate but excluding CO2 fertilization effects on crop yield.

**Table 4.5: Impacts of climate change on the production potential of major rain-fed cereals in current cultivated land (% change with respect to current climate)**

| Region | CSIRO A2 versus Reference Climate (% change; with $CO_2$ fertilization) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Rain-fed Wheat | | | Rain-fed Maize | | | Rain-fed Sorghum | | |
| | 2020s | 2050s | 2080s | 2020s | 2050s | 2080s | 2020s | 2050s | 2080s |
| North America | 3 | 10 | 7 | 3 | 9 | 7 | 15 | 25 | 28 |
| Europe | 2 | 3 | -1 | 40 | 47 | 47 | 31 | 41 | 37 |
| Russian Fed. | 4 | 4 | -15 | 64 | 79 | 69 | 60 | 75 | 70 |
| Central America | -19 | -36 | -53 | 2 | 7 | 13 | 3 | 10 | 17 |
| South America | -12 | -19 | -30 | 2 | 3 | 4 | 8 | 10 | 15 |
| Oceania & Polynesia | 4 | 11 | 4 | 19 | 31 | 57 | 4 | 9 | 7 |
| North Afr & West Asia | 2 | -1 | -12 | 42 | 71 | 69 | 11 | 17 | 13 |
| North Africa | 1 | 4 | -18 | 66 | 160 | 183 | 12 | 31 | 20 |
| West Asia | 3 | -3 | -9 | 33 | 38 | 26 | 11 | 12 | 9 |
| Sub-Saharan Africa | -27 | -45 | -69 | 0 | -2 | -7 | 1 | 0 | -4 |
| Eastern Africa | -30 | -48 | -72 | 3 | 4 | -1 | 4 | 4 | -2 |
| Middle Africa | -34 | -58 | -84 | 2 | 2 | -1 | 5 | 6 | 7 |
| Southern Africa | -18 | -34 | -58 | -26 | -47 | -51 | -24 | -41 | -45 |
| Western Africa | -76 | -98 | -100 | 0 | -1 | -7 | 1 | 2 | -1 |
| Asia | -8 | -23 | -45 | 0 | 1 | 0 | 3 | 5 | 4 |
| Southeast Asia | -35 | -48 | -79 | 0 | 0 | 1 | -2 | -5 | -5 |
| South Asia | -22 | -45 | -70 | -1 | -3 | -5 | 1 | 0 | 0 |
| East Asia & Japan | -7 | -21 | -38 | 2 | 5 | 2 | 5 | 11 | 11 |
| Central Asia | 19 | 18 | -7 | 34 | 87 | 110 | 27 | 35 | 31 |
| Developed | 3 | 7 | 0 | 23 | 30 | 29 | 27 | 38 | 37 |
| Developing | -10 | -23 | -42 | 1 | 1 | 0 | 4 | 5 | 4 |
| World | -1 | -3 | -13 | 8 | 10 | 9 | 12 | 16 | 16 |

Source: GAEZ 2009 simulations; May 2009.

**Table 4.6: Impacts of climate change on the production potential of major rain-fed cereals in current cultivated land (% change with respect to current climate)**

| Region | CSIRO A2 versus Reference Climate (% change; without $CO_2$ fertilization) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Rain-fed Wheat | | | Rain-fed Maize | | | Rain-fed Sorghum | | |
| | 2020s | 2050s | 2080s | 2020s | 2050s | 2080s | 2020s | 2050s | 2080s |
| North America | 0 | 4 | -3 | 2 | 5 | 2 | 12 | 20 | 21 |
| Europe | -1 | -3 | -11 | 37 | 42 | 40 | 29 | 35 | 30 |
| Russian Fed. | 1 | -2 | -23 | 61 | 73 | 62 | 57 | 68 | 62 |
| Central America | -21 | -39 | -57 | 0 | 3 | 7 | 1 | 6 | 11 |
| South America | -14 | -23 | -36 | 0 | -1 | -1 | 6 | 6 | 10 |
| Oceania & Polynesia | 2 | 6 | -4 | 17 | 27 | 50 | 2 | 6 | 3 |
| North Afr & West Asia | 0 | -7 | -19 | 41 | 66 | 62 | 9 | 14 | 8 |
| North Africa | -2 | -2 | -25 | 64 | 153 | 171 | 10 | 27 | 15 |
| West Asia | 0 | -9 | -17 | 32 | 34 | 21 | 9 | 8 | 5 |
| Sub-Saharan Africa | -28 | -47 | -72 | -2 | -5 | -12 | -1 | -3 | -8 |
| Eastern Africa | -31 | -50 | -74 | 1 | 0 | -7 | 2 | 0 | -7 |
| Middle Africa | -35 | -60 | -85 | 1 | -1 | -6 | 3 | 3 | 2 |
| Southern Africa | -20 | -37 | -61 | -27 | -49 | -54 | -25 | -43 | -48 |
| Western Africa | -76 | -98 | -100 | -1 | -5 | -12 | 0 | -2 | -6 |
| Asia | -10 | -27 | -49 | -1 | -2 | -5 | 2 | 1 | -1 |
| Southeast Asia | -36 | -51 | -80 | -2 | -4 | -4 | -4 | -7 | -9 |
| South Asia | -23 | -47 | -72 | -3 | -7 | -10 | -1 | -4 | -5 |
| East Asia & Japan | -9 | -24 | -43 | 0 | 1 | -3 | 3 | 7 | 5 |
| Central Asia | 17 | 12 | -14 | 33 | 81 | 101 | 25 | 31 | 26 |
| Developed | 0 | 0 | -10 | 21 | 25 | 22 | 25 | 32 | 30 |
| Developing | -13 | -27 | -46 | -1 | -2 | -5 | 2 | 1 | -1 |
| World | -4 | -8 | -21 | 6 | 6 | 4 | 10 | 12 | 10 |

Source: GAEZ 2009 simulations; May 2009.

The results of the AEZ analysis, using the HadCM3 and CSIRO climate projections for IPCC A2 emissions pathways, suggest three conclusions: (i) there are a number of regions where climate change poses a significant threat for food production; (ii) the global balance of food production potential for rain-fed cereal production of current cultivated land may slightly improve in the short-term; effective agronomic adaptation by farmers to a changing climate and the actual strength of the so-called CO2 fertilization effect on crop yields will be decisive factors to realize a positive global balance of food production potential; and (iii) beyond 2050, negative impacts of warming dominate and cause a rapid decrease of the crop production potential in most regions and for the global aggregate.

In the short-term, policy-makers need to strengthen farmers' adaptation capacity and must support strategies to cope with climate variability and extreme events, which may severely affect the welfare of the most vulnerable populations. In the long run, climate change, if not halted, will result in irreparable damages to arable land, water, and biodiversity resources, with eventually serious consequences for food production and food security.

## 5. IMPACTS OF CLIMATE CHANGE ON WORLD FOOD SYSTEM INDICATORS

The evaluation of the potential impacts of climate change on production and trade of agricultural commodities, in particular on cereals, was carried out in two steps. First, simulations were undertaken where current climate and atmospheric conditions would prevail. Second, yield impacts due to temperature and CO2 changes, as derived from the agro-ecological assessment, were simulated with the world food system model and compared to the respective outcomes without climate change. Assumptions and results for the reference projection were presented in section 3.

Data on crop yield changes were estimated with AEZ for different scenarios of climate change and were compiled to provide yield-impact parameterizations for the countries or regions covering the world in the world food system model. Yield variations caused by climate change were introduced into the yield response functions by means of a multiplicative factor impacting upon the relevant parameters in the mathematical representation (i.e. the crop yield functions).

Exogenous variables, population growth and technical progress, were left at the levels specified in the respective reference projections. No specific adjustment policies to counteract altered performance of agriculture have been assumed beyond the farm-level adaptations resulting from economic adjustments of the individual actors in the national models The adjustment processes taking place in the different scenarios are the outcome of the imposed yield changes triggering changes in national production levels and costs, leading to changes of agricultural prices in the international and national markets; this in turn affects investment allocation and labor migration between sectors as well as reallocation of resources within agriculture.

### Agricultural prices

Table 5.1 summarizes the outcomes of scenario simulations with regard to agricultural prices. It shows the price index deviation, in percent, relative to equilibrium prices calculated in the reference projection without climate change. Price indexes were calculated for (i) cereals, (ii) over all crops, and (iii) aggregate for crops and livestock production. Climate scenarios were constructed for both the HadCM3 (Gordon et al., 2000; Pope et al.; 2000) and CSIRO (Gordon and O'Farrell, 1997; Hirst et al., 1997) GCM model outputs of IPCC SRES A2 simulations. Results for simulations using the Hadley Centre climate model outputs are given with and without considering the effects of CO2 fertilization on crop yields. It should be noted again that the climate scenarios do not take into account the possibility of increased climate variability. Also, the results assume successful and full agronomic adaptation by farmers (as discussed in section 3).

**Table 5.1: Impact of climate change on agricultural prices**

| Scenario | CO2 fertilization | Change of Price Index relative to Reference Climate (percent) | | | |
|---|---|---|---|---|---|
| | | 2020 | 2030 | 2050 | 2080 |
| **Cereals** | | | | | |
| Hadley A2 | with | -4 | -1 | -1 | 23 |
| Hadley A2 | without | 1 | 6 | 10 | 44 |
| CSIRO A2 | with | 1 | 3 | 2 | 21 |
| **Crops** | | | | | |
| Hadley A2 | with | -4 | -3 | -3 | 11 |
| Hadley A2 | without | 0 | 4 | 7 | 27 |
| CSIRO A2 | with | -1 | 0 | 0 | 9 |
| **Agriculture** | | | | | |
| Hadley A2 | with | -3 | -2 | -2 | 8 |
| Hadley A2 | without | 0 | 3 | 5 | 20 |
| CSIRO A2 | with | -1 | 1 | 0 | 7 |

Source: IIASA world food system simulations, May 2009.

Overall, there is only a small impact resulting on world market prices from climate change yield impacts in the decades until about mid-century. In fact, the CO2 fertilization effect and assumed autonomous adaptation to climate change more than compensate for negative yield impacts. Beyond 2050, negative yield impacts would dominate and cause price increases, for cereals in the 2080s simulated in the order of 20 percent. When CO2 fertilization effects are disregarded prices start to increase gradually already in the early decades and increases are projected to accelerate after 2050. In this case medium term effects on cereal prices would be in the order of 10 percent; in the long term, i.e. by 2080, simulated price increases approach 50 percent.

## Cereal production and consumption

The impact of climate change on the production of cereals, resulting both from changes in land productivity as well as economic responses of actors in the system, is summarized in Table 5.2.

The model results present a fairly consistent response and geographical patterns in regional cereal production to climate change. At global level, taking into account economic adjustment of actors and markets, cereal production until 2050 falls within 1 percent of the results for the respective reference simulations without climate change when $CO_2$ fertilization and agronomic adaptation are considered. For the 2080s the percentage losses exceed 2 percent for both HadCM3 and CSIRO climate scenarios. When $CO_2$ fertilization effects are not considered then simulated global cereal production is 1.4 percent less than in the baseline in 2050 and more than 4.3 percent below in 2080 (some 165 million tons).

Developing countries consistently experience significant reductions of cereal production in all climate scenarios in the long-term by 2080s. Among the most severely affected regions are South Asia and Sub-Saharan Africa.

**Table 5.2: Impacts of climate change scenarios on cereal production**

| | Change in cereal production compared to the Reference scenario (percent) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hadley A2 | | | | CSIRO A2 | | | | Hadley A2, without CO2 fertilization | | | |
| | **2020** | **2030** | **2050** | **2080** | **2020** | **2030** | **2050** | **2080** | **2020** | **2030** | **2050** | **2080** |
| North America | 1.9 | -2.9 | -2.9 | -0.8 | 2.8 | 0.1 | 5.8 | 7.1 | 0.9 | -3.9 | -4.6 | -4.8 |
| Europe & Russia | 0.8 | 2.0 | 1.8 | 1.5 | 0.5 | 1.7 | 1.0 | 3.1 | 0.1 | 1.0 | 0.1 | -1.1 |
| Pacific OECD | -2.2 | 2.4 | 9.5 | 14.0 | 2.5 | 6.9 | 7.0 | 18.2 | -1.8 | 2.8 | 9.3 | 13.6 |
| Africa, sub-Saharan | -1.3 | 0.3 | -2.0 | -2.5 | -0.6 | 0.4 | -2.9 | -7.2 | -0.9 | 0.6 | -2.0 | -2.2 |
| Latin America | 0.9 | 4.7 | 5.5 | 6.0 | 1.3 | 3.5 | -0.7 | 0.9 | 1.3 | 5.0 | 6.4 | 8.0 |
| Mid. East & N. Africa | -0.5 | 0.7 | 1.1 | -1.0 | 5.2 | 7.7 | 7.4 | -1.0 | -0.7 | 0.3 | 0.3 | -2.2 |
| Asia, East | 0.1 | 0.7 | 2.0 | -2.8 | -2.2 | -2.8 | -3.4 | -7.2 | -0.6 | -0.4 | 0.2 | -5.3 |
| Asia, South/Southeast | -1.3 | -1.3 | -3.7 | -12.2 | -4.8 | -5.9 | -8.9 | -12.8 | -1.6 | -1.9 | -4.6 | -13.2 |
| Rest of World | -1.6 | -1.7 | -3.1 | -4.6 | -2.4 | -2.8 | -3.4 | -4.6 | -2.6 | -3.4 | -6.1 | -9.0 |
| Developed | 1.2 | -0.7 | -0.3 | 0.5 | 1.7 | 1.1 | 4.2 | 5.9 | 0.3 | -1.7 | -2.0 | -2.8 |
| Developing | -0.3 | 0.7 | 0.2 | -3.9 | -1.8 | -1.8 | -4.2 | -7.3 | -0.6 | 0.2 | -0.6 | -4.9 |
| World | 0.3 | 0.1 | -0.2 | -2.2 | -0.4 | -0.6 | -0.8 | -2.1 | -0.3 | -0.7 | -1.4 | -4.3 |

Source: IIASA world food system simulations, May 2009.

In the world of the 2050s and 2080s, consumers are assumed to be much richer than today and are largely separated from agricultural production processes. They earn their incomes mainly in the non-agricultural sector. Therefore, aggregate changes in consumption depend mainly on food prices and income levels rather than on local production conditions. Table 5.3 summarizes the changes in total cereal consumption (i.e. including food, feed, industrial and seed use, and waste) occurring in the world food system simulations in response to climate change.

**Table 5.3: Impacts of climate change scenarios on cereal consumption**

| | Change in cereal consumption compared to the Reference scenario (percent) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hadley A2 | | | | CSIRO A2 | | | | Hadley A2, without $CO_2$ fertilization | | | |
| | **2020** | **2030** | **2050** | **2080** | **2020** | **2030** | **2050** | **2080** | **2020** | **2030** | **2050** | **2080** |
| North America | 0.7 | 0.3 | 0.5 | -0.4 | 0.1 | -0.3 | 1.2 | 1.0 | -0.1 | -0.8 | -1.2 | -3.6 |
| Europe & Russia | 0.8 | 0.3 | 0.1 | -1.2 | 0.1 | -0.4 | -0.7 | -1.4 | 0.1 | -0.6 | -1.4 | -3.6 |
| Pacific OECD | 2.2 | 0.3 | 1.5 | -4.5 | 0.3 | -1.5 | -0.4 | -5.0 | 0.3 | -2.1 | -3.2 | -12.4 |
| Africa, sub-Saharan | 0.4 | 0.1 | -0.1 | -4.2 | -0.2 | -0.5 | -0.6 | -4.0 | -0.2 | -0.7 | -1.4 | -6.8 |
| Latin America | 0.8 | 0.3 | -0.1 | -2.6 | 0.1 | -0.3 | -0.5 | -2.3 | 0.1 | -0.4 | -0.6 | -3.4 |
| Mid. East & N. Africa | 0.2 | 0.0 | -0.1 | -2.6 | -0.2 | -0.3 | -0.2 | -2.4 | -0.3 | -0.7 | -1.1 | -4.4 |
| Asia, East | 0.0 | -0.1 | 0.1 | -1.0 | -0.4 | -0.8 | -1.4 | -0.8 | -0.2 | -0.4 | -0.7 | -1.6 |
| Asia, South/Southeast | 0.0 | -1.1 | -1.0 | -3.9 | -0.9 | -1.9 | -1.5 | -3.6 | -0.7 | -1.9 | -2.0 | -5.3 |
| Rest of World | 0.3 | 0.0 | -0.1 | -0.9 | -0.1 | -0.4 | -0.4 | -0.9 | -0.1 | -0.4 | -0.7 | -1.7 |
| Developed | 0.7 | 0.2 | 0.2 | -1.6 | 0.0 | -0.5 | 0.1 | -0.8 | 0.0 | -0.9 | -1.7 | -4.7 |
| Developing | 0.2 | -0.2 | -0.2 | -2.5 | -0.4 | -0.9 | -1.1 | -2.5 | -0.3 | -0.8 | -1.1 | -3.8 |
| World | 0.4 | -0.1 | -0.1 | -2.1 | -0.2 | -0.7 | -0.7 | -2.0 | -0.2 | -0.8 | -1.2 | -4.0 |

Source: IIASA world food system simulations, May 2009.

Table 5.3 shows a fairly uniform decline in cereal consumption in 2080s of about 2 percent globally (i.e. about 80 million tons reduction compared to 3.8 billion tons consumption in the reference simulation) and about 2.5 percent in developing countries for both climate model scenarios and with $CO_2$ fertilization effects accounted for. In the HadCM3 simulation without $CO_2$ fertilization effects the reduction is about 4 percent compared to a reference scenario without climate change.

### Risk of hunger

Estimates of the number of *people at risk of hunger* vary greatly according to socioeconomic development trajectories, in particular assumed income levels and income distribution, and population numbers. Assumptions and results for the reference simulation were presented in section 3.According to this reference projection, the estimated number of undernourished would slowly decrease between 2010 to 2020 (to about 900 million), would fall to 760 million by 2030, to 530 million by 2050, and to some 150 million by 2080. For comparison, the changes in the estimated number of people at risk of hunger, at different time points and for three climate scenarios, are summarized in Table 5.4. It is worth noting that in these simulations the recorded climate change impacts on undernourishment are relatively small; in the early periods due to relatively small global yield impacts and small resulting price effects, in the long-term, when yield impacts become substantial, due to the improved socio-economic conditions and small absolute number of undernourished.

**Table 5.4: Impact of climate change on risk of hunger**

| | Change in number of people at risk of hunger compared to Reference scenario (millions) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Hadley A2 | | | CSIRO A2 | | | Hadley A2, without $CO_2$ fertilization | | |
| | **2030** | **2050** | **2080** | **2030** | **2050** | **2080** | **2030** | **2050** | **2080** |
| Africa, sub-Saharan | 0 | 1 | 17 | 1 | 0 | 10 | 4 | 9 | 28 |
| Asia | 4 | -2 | 5 | 22 | 4 | 3 | 27 | 18 | 14 |
| Rest of World | -2 | -2 | 6 | 1 | 0 | 5 | 5 | 9 | 16 |
| World | 1 | -3 | 28 | 24 | 4 | 19 | 35 | 36 | 57 |

Source: IIASA world food system simulations, May 2009.

In summary, climate-change impacts on agriculture will increase the number of people at risk of hunger. This impact will be of global significance if imposed on an already high level of undernourishment. In the socioeconomic development scenario underlying the projections of Agriculture Toward 2030/50, with solid economic growth and a transition to stable population levels after 2050, poverty, and with it hunger – though negatively affected by climate change – is a much less ubiquitous phenomenon than it is today.

### Cultivated land

The results for changes in cultivated land use are summarized in Table 5.5 and results for impacts on the level of harvested area are shown in Table 5.6. As for other food system indicators discussed before, the changes in net cultivated area simulated in response to climate change scenarios up to 2050 are relatively small. Even when CO2 fertilization effects are not taken into account the additional land put under cultivation globally is less than 10 million hectares. Only after 2050, when climate change impacts become increasingly negative for crop yields, more additional land is put into production compared to the reference climate simulations. In 2080, the estimated increase is 10-13 million hectares of cultivated land in simulations with CO2 fertilization effects accounted for, and 26 million hectares in the case without CO2 fertilization. It should be noted that these estimated changes are net global effects and should not be confused with gross land conversion, which can be expected to be a lot higher in response to climate change impacts and adaptation efforts.

**Table 5.5: Impact of climate change on net use of cultivated land**

| | Change in Cultivated Land compared to Reference scenario (million hectares) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Hadley A2 | | | CSIRO A2 | | | Hadley A2, without $CO_2$ fertilization | | |
| | **2030** | **2050** | **2080** | **2030** | **2050** | **2080** | **2030** | **2050** | **2080** |
| Africa, sub-Saharan | 0 | -1 | 3 | 1 | 0 | 2 | 1 | 2 | 7 |
| Latin America | -1 | -2 | 1 | 1 | 1 | 3 | 1 | 3 | 8 |
| Other Developing | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 4 |
| Developed | 1 | 1 | 5 | 3 | 3 | 6 | 2 | 2 | 6 |
| Developing | -2 | -4 | 5 | 2 | 1 | 7 | 3 | 5 | 19 |
| World | -1 | -3 | 10 | 4 | 4 | 13 | 5 | 8 | 26 |

Source: IIASA world food system simulations, May 2009.

**Table 5.6: Impact of climate change on harvested area**

| | Change in Harvested Area compared to Reference scenario (million hectares) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Hadley A2 | | | CSIRO A2 | | | Hadley A2, without $CO_2$ fertilization | | |
| | **2030** | **2050** | **2080** | **2030** | **2050** | **2080** | **2030** | **2050** | **2080** |
| Africa, sub-Saharan | -1 | -2 | 4 | 1 | 0 | 2 | 2 | 2 | 10 |
| Latin America | -1 | -2 | 1 | 1 | 1 | 4 | 1 | 4 | 10 |
| Other Developing | -1 | -2 | 3 | -1 | -1 | 1 | 1 | 2 | 9 |
| Developed | -1 | 0 | 6 | 3 | 3 | 6 | 2 | 4 | 9 |
| Developing | -3 | -5 | 8 | 1 | 0 | 7 | 4 | 8 | 29 |
| World | -3 | -6 | 14 | 4 | 2 | 14 | 6 | 12 | 39 |

Source: IIASA world food system simulations, May 2009.

## 6. IMPACTS OF BIOFUEL EXPANSION ON WORLD FOOD SYSTEM INDICATORS

Biofuels, mainly ethanol and biodiesel, are produced from a number of agricultural crops that are also important for the provision of food and feed. At present biofuels production is spreading around the world in a growing number of countries.

A number of developed countries have embraced the apparent win-win opportunity to foster the development of biofuels in order to respond to the threats of climate change, to lessen their dependency on oil and to contribute to enhancing agriculture and rural development, which is, of course, also of concern to developing countries where more than 70 percent of the poor reside in rural areas. Countries such as the United States, Member States of the European Union, China, India, Indonesia, South Africa and Thailand have all adopted policy measures and set targets for the development of biofuels.

The driving forces of biofuels expansion have been foremost huge subsidies and the mandates and targets set by national governments. Whilst the justification of biofuels targets to enhance fuel energy security and to contribute to climate change mitigation and agricultural rural development is appealing, the reality is complex since the consequences of biofuels developments result in local, national, regional and global impacts across interlinked social, environmental and economic domains, well beyond the national setting of domestic biofuels targets.

The conditioning factors of biofuels development at national level include the technical capabilities of biofuels as blending agents, the agro-ecological conditions and availability of land resources, the suitability, productivity and production potential of various biofuel feedstocks, the prospects for regional and international trade of biofuels, and the potential savings of greenhouse gas emissions and climate change mitigation.

### 6.1 Overview of biofuels scenarios

The biofuel scenarios used in the model simulations were designed to cover a wide and plausible range of possible future demand for biofuels. Scenario specification consisted of three steps: first, an overall energy scenario was selected, detailing as one of its components the regional and global use of transport fuels. Second, pathways were chosen as to the role played by biofuels in the total use of transport fuels. Third, the assumptions were made explicit as to the role and dynamics of second-generation biofuel production technologies in each scenario, or conversely, what fraction of total biofuel production was expected to be supplied by first-generation feedstocks, i.e. being based on conventional agricultural crops (maize, sugar cane, cassava, oilseeds, palm oil, etc.). Data on current biofuel feedstock use, and assumptions and specification of biofuel scenarios used for the scenario analysis are described in detail in Fischer et al. (2009).

### Future projections of transport fuel use

For describing regional energy futures we used the World Energy Outlook (WEO 2008) reference scenario published by the International Energy Agency (IEA, 2008a). In the WEO 2008 Reference Scenario, world primary energy demand grows by 1.6 percent per year on average in 2006-2030, from 11,730 Mtoe to just over 17,000 Mtoe (i.e. by about 45 percent). This projection embodies the effects of government policies and measures that were enacted or adopted up to mid-2008. The IEA World Energy Model (WEM) - a large-scale mathematical system designed to replicate how energy markets function – has been the principal tool used to generate the sector-by-sector and fuel-by-fuel projections by region or country (IEA, 2008a).

World primary oil demand in the WEO reference scenario increases from 76.3 million barrels per day in 2000 to 106.4 million barrels per day in 2030, an increase by about 40 percent. The transport sector consumes about three-quarters of the projected increase in world oil demand (IEA, 2008a).

**Table 6.1: Final consumption of transport fuels by region**

| WEO | Million tons oil equivalent (Mtoe) | | | |
|---|---|---|---|---|
| | **2000** | **2020** | **2030** | **2050** |
| North America | 655 | 773 | 773 | 781 |
| Europe & Russia | 519 | 658 | 652 | 609 |
| Pacific OECD | 105 | 110 | 99 | 93 |
| Rest of World | 6 | 16 | 24 | 36 |
| Africa | 45 | 69 | 80 | 122 |
| Asia, East | 114 | 337 | 495 | 625 |
| Asia, South | 111 | 224 | 322 | 544 |
| Latin America | 149 | 253 | 285 | 332 |
| Middle East & N. Africa | 108 | 214 | 259 | 342 |
| Developed | 1236 | 1480 | 1460 | 1417 |
| Developing | 576 | 1174 | 1529 | 2068 |
| World* | 1962 | 2830 | 3171 | 3750 |

* World totals include international marine bunkers and international aviation

In terms of total final consumption of transport fuel the scenario projects an increase from 1962 Mtoe to 3171 Mtoe for the period 2000-2030. Regional totals of transport fuel consumption, derived from the WEO reference scenario for the period 1990 to 2030 and extrapolated to 2050 for use in the simulations of the world food system, are summarized in Table 6.1.

### Biofuels use and share in total final consumption of transport fuels

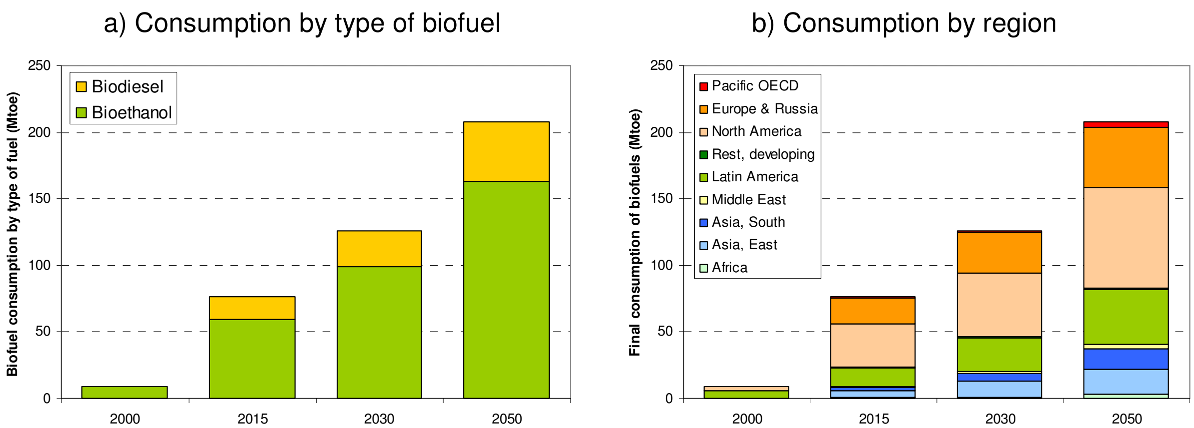
The level and regional pattern of total transport fuel consumption, as presented above, has been applied in all biofuels simulations with the world food system model discussed in this paper. Regarding the use of biofuels we implemented two alternative scenarios: (i) biofuel expansion based on the WEO 2008 projections, and (ii) fast expansion of biofuel production in accordance with the mandates and targets announced by several developed and developing countries. In addition, a number of sensitivity scenarios were specified to gain understanding over a wide range of possible biofuel production levels to 2050.

#### *Biofuels consumption in the WEO scenario*

Final demand of biofuels in 1990 was about 6 Mtoe, with two-thirds being produced in Brazil at that time. In 2006 world biofuel consumption reached 24.4 Mtoe, with the United States being both the largest producer and consumer. In our implementation for 2020, final consumption of biofuels in the developed countries is projected at 63 Mtoe, with the United States and EU-27 accounting for 90 percent of this use. In 2030 the final consumption of biofuels reaches 79 Mtoe in the developed world. For 2030 and 2050 we use projections of biofuel consumption in developed countries that respectively amount to 79 Mtoe and 124 Mtoe[3].

Amongst the developing countries Brazil has been the pioneer producing about 5 Mtoe in 1990 and this is projected to increase to some 18 Mtoe in 2020. Total biofuel consumption in developing countries starts from about 5.5 Mtoe in 2000, increases to 31 Mtoe by 2020, and reaches 46 Mtoe in 2030. Biofuel use in developing countries in this scenario is dominated by Brazil throughout the projection period. Brazil, China and India together account for about 80 percent of biofuel use in developing countries, a combined share that decreases slightly to about 75 percent in 2050. Figure 6.1 shows the dynamics of projected biofuel consumption in the WEO-based scenario; panel a) indicates the fuel split, panel b) shows a distribution by region.

**Figure 6.1: Final consumption of biofuels in the WEO scenario**




Source: Fischer et al., 2009.

*Biofuels consumption in the TAR scenario*

The WEO 2008 report states that "… assume in the Reference Scenario that the biofuel mandates in China and the European Union will be met after a lag of a few years but that biofuels in the United States in 2030 will attain only about 40 percent of the very ambitious target in the 2007 Energy Independence and Security Act. Asia and OECD Europe experience faster rates of growth, but in absolute terms these increases trail those in the larger North American market. Biofuels demand in the OECD Pacific region remains modest. Growth in Latin America is moderate, a consequence of the sizeable share of the market in Brazil already held by biofuels." (IEA, 2008a, p.172)

A number of countries have defined mandatory, voluntary or indicative targets for transport fuels (see Table 6.2). To gain a better understanding of the possible impacts on the world food system that may result from implementation and full achievement of the specified targets, a second biofuels scenario, more ambitious in terms of biofuel expansion than the WEO outlook, was implemented and termed target scenario (TAR). In this TAR scenario, final consumption of biofuels increases to 189 Mtoe in 2020, about twice the value achieved in WEO, and climbs to 295 Mtoe and 424 Mtoe respectively in 2030 and 2050. As hardly any country has announced biofuel targets beyond ca. 2020, this scenario should be interpreted as the extension of a rapid and ambitious biofuel development pathway based on targets announced up to 2020. It approximately doubles biofuel consumption compared to the WEO

[3] Minor adjustments to values published in the WEO 2008 for developed countries have been implemented for use in the world food system simulations.

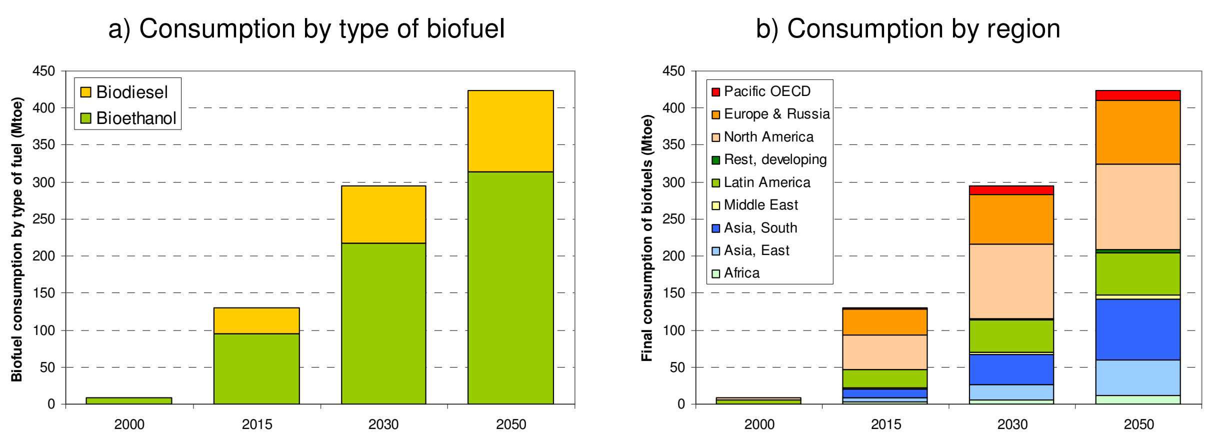
projections. Figure 6.2 shows distribution of biofuel consumption by type and region for the TAR scenario.

**Table 6.2: Voluntary and mandatory targets for transport fuels in major countries**

| Country/Region | Mandatory, voluntary or indicative target |
|---|---|
| Australia | At least 350 million liters of biofuels by 2010 |
| Canada | 5% renewable content in gasoline by 2010 |
| European Union | 5.75% by 2010, 10% by 2020 |
| Germany | 6.25% by 2010, 10% by 2020 |
| France | 7% by 2010, 10% by 2015, 10 percent by 2020 |
| Japan | 0.6% of auto fuel by 2010; a goal to reduce fossil oil dependence of transport sector from 98% to 80% by 2030 |
| New Zealand | 3.4% target for both gasoline and diesel by 2012 |
| United States | 12 billion gallons by 2010, rising to 20.5 billion gallons by 2015 and to 36 billion gallons by 2022 (with 16 billion gallons from advanced cellulosic ethanol) |
| Brazil | Mandatory 25% ethanol blend with gasoline; 5 percent biodiesel blend by 2010. |
| China | 2 million tons ethanol by 2010 increasing to 10 million tons by 2020; 0.2 million tons biodiesel by 2010 increasing to 2 million tons by 2020. |
| India | 5% ethanol blending in gasoline in 2008, 10% as of 2009; indicative target of 20% ethanol blending in gasoline and 20% biodiesel blending by 2017. |
| Indonesia | 2% biofuels in energy mix by 2010, 3% by 2015, and 5% by 2020. |
| Thailand | 2% biodiesel blend by 2008, 10% biodiesel blend by 2012; 10% ethanol blend by 2012. |
| South Africa | 2% of biofuels by 2013 |

Source: Fischer et al., 2009.

**Figure 6.2: Final consumption of biofuels in the TAR scenario**




Source: Fischer et al., 2009.

It is worth noting that in this TAR scenario the share of developing countries in total biofuel consumption is higher than in the WEO scenario due to considering fairly ambitious proposed or announced targets for China, India, Indonesia and Thailand. Due to this change in the regional distribution, the share of biodiesel in total biofuels increases somewhat compared to WEO.

### *Share of biofuel consumption in total transport fuels*

In the developed world, the projected share of biofuel consumption in total transport fuels use in 2020 amounts to 4.3 percent in the WEO scenario. By 2030 this share increases to 5.5 percent. For the developing world the WEO scenario projects a biofuels share in total transport fuel use in 2020 and 2030 at 2.7 percent and 3.0 percent respectively. At the global level this share comes to 3.5 percent in 2020 and 4.2 percent in 2030. It increases to 6 percent in 2050[4]. With a road transport share of 70 percent to 75 percent of total transport fuel use, biofuels would account for respectively 4.5 percent, 5.4 percent, and 7.6 percent of road transport in 2020, 2030 and 2050[5].

## Share of second-generation biofuels in total biofuel consumption

In recent years second-generation biofuels, i.e. fuels produced from woody or herbaceous non-food plant materials as feedstocks, have attracted great attention because they are seen as superior to conventional feedstocks in terms of their greenhouse gas saving potential, but even more so because of their potential for production on 'non-food' land.

It is widely acknowledged that major technological breakthroughs will be required to improve feedstock materials and the efficiency of the conversion process before second-generation biofuels will be able to make a significant contribution.

**Table 6.3: Scenario variants for share of second-generation biofuels in total**

| Scenario variant | Region | Assumed share of second-generation ethanol in total bioethanol (%) | | | |
|---|---|---|---|---|---|
| | | 2015 | 2020 | 2030 | 2050 |
| WEO-V1, TAR-V1 | United States | Starts | 7.5 | 25 | 50 |
| | Other OECD | None | Starts | 12.5 | 33 |
| | Russia | None | Starts | 5 | 20 |
| | Brazil/China/India | None | Starts | 5 | 20 |
| | Other developing | None | None | None | None |
| WEO-V2, TAR-V2 | All countries | None | None | Starts | 10 |
| WEO-V3 | United States | 10 | 24 | 40 | 66 |
| | EU-27 | None | 10 | 33 | 50 |
| | Other OECD | None | 10 | 33 | 50 |
| | Russia | None | 5 | 20 | 40 |
| | China/India | Starts | 5 | 20 | 40 |
| | Other developing | 0 | 0 | 10 | 20 |
| TAR-V3 | United States | 10 | 35 | 55 | 70 |
| | EU-27 | 10 | 31 | 47 | 67 |
| | Other OECD | 10 | 31 | 47 | 67 |
| | Russia | Starts | 10 | 33 | 50 |
| | China/India | Starts | 10 | 33 | 50 |
| | Other developing | 0 | Starts | 10 | 33 |

Source: Fischer et al., 2009.

For completing the definition of biofuel scenarios in this assessment, three variants were specified for both the WEO and TAR biofuel scenario. They represent alternative views/expectations on the dynamics of technology deployment for second-generation fuels. The variants are defined by describing different pathways for the share

[4] Share in world total excludes international marine bunkers.
[5] Recent industry tests suggest that biofuels could also be successfully used in aviation.

of second-generation fuels in total biofuel consumption. Specification was done by broad regions and follows simple and transparent assumptions. The assumptions used for ethanol are summarized in Table 6.3.

The variant V1 (both for WEO-V1 and TAR-V1) assumes that second-generation biofuel technologies will be available in the United States for commercial deployment as of 2015. By 2020, the lignocelluloses conversion will contribute 7.5 percent of total bioethanol, and by 2030 this share will increase to 25 percent. In other OECD countries it is assumed for this scenario variant that second-generation conversion plants will take off as of 2020, occupying a share of 12.5 percent by 2030. The biofuel champions among developing countries (Brazil, China and India) will also start using second-generation technologies in 2020, but deployment would follow a somewhat slower path to contribute only 5 percent of ethanol in 2030. The V2 variant portrays a delayed development of second-generation technologies. Conversion plants are assumed to become available only by 2030, implying that all transport biofuel production up to 2030 relies in this variant V2 on conventional feedstocks.

Finally, scenario variant V3 assumes an early and accelerated deployment of second-generation technologies. In scenario variant TAR-V3 the biochemical ethanol processing and FT-diesel plants become already available in 2010 and contribute in OECD countries a share of 10 percent to biofuels by 2015, increasing to more than 30 percent in 2020. In 2030, second-generation biofuels account for about 50 percent of total biofuels in developed countries, and more than two thirds in 2050. China and India follow this development with a short delay. The share of second-generation biofuels in these two countries is set at 10 percent in 2020, one-third in 2030, and half of total biofuel production in 2050. Other developing countries start deploying second-generation plants in 2020 and reach a share of 10 percent and 33 percent respectively in 2030 and 2050.

At the aggregate global level, second-generation biofuel shares in scenario variant WEO-V1 are 3 percent, 13 percent and 30 percent in 2020, 2030 and 2050 respectively. In scenario variant TAR-V1 these shares are respectively 2, 12 and 26 percent, i.e. somewhat lower due to the higher shares in total production achieved by developing countries[6] in the TAR scenario as compared to the WEO scenario. For variant TAR-V3, with an assumed accelerated second-generation development and deployment path, the respective shares are 22, 38, and 55 percent.

### Sensitivity analysis with respect to share of biofuels in total transport fuels

In addition to the WEO and TAR biofuel scenarios introduced above, four sensitivity scenarios (SNS) were computed in order to systematically scan the world food system model outcomes for a broad range of imposed first-generation biofuel production levels, from 2-8 percent in 2020, 2.5-10 percent in 2030, and 3-12 percent in 2050. Table 6.4 summarizes for different scenarios and time points the assumed share of first-generation biofuels in total transport fuel use.

**Table 6.4: First-generation biofuels assumed in sensitivity scenarios**

| Scenario | Share in total transport fuels (percent) | | | 1st generation biofuel consumption (Mtoe) | | |
|---|---|---|---|---|---|---|
| | 2020 | 2030 | 2050 | 2020 | 2030 | 2050 |
| SNS-V1 | 2 | 2.5 | 3 | 54 | 76 | 106 |
| SNS-V2 | 4 | 5 | 6 | 107 | 151 | 211 |
| SNS-V3 | 6 | 7.5 | 9 | 161 | 227 | 317 |
| SNS-V4 | 8 | 10 | 12 | 214 | 302 | 423 |

Source: Fischer et al., 2009.

[6] As developing countries on average are assumed to have a lower share of second-generation biofuels in total biofuel production than developed countries, their stronger participation in global biofuel production implies a lower global average share of second-generation fuels.

### First-generation biofuel feedstocks demanded in selected biofuel scenarios

Estimates for 2008 indicate that about 80-85 million tons of cereals were used for ethanol production, mainly maize in the USA, and about 10 million tons of vegetable oil for production of biodiesel, dominated by the EU. In the reference scenario FAO-REF-01 these amounts are kept constant for the entire remaining simulation period to 2050. The amounts increase in both the WEO and TAR scenario variants. The time path in each scenario variant depends on the level and geographical distribution of biofuel production and assumptions regarding availability of second-generation technologies. The amount of cereals and vegetable oil required for transport biofuel production in 2020, 2030 and 2050 in selected biofuel scenarios is shown in Table 6.5.

**Table 6.5: Use of cereals and vegetable oil for biofuel production in different scenarios**

| Scenario | Cereals (million tons) | | | Vegetable oil (million tons) | | |
|---|---|---|---|---|---|---|
| | 2020 | 2030 | 2050 | 2020 | 2030 | 2050 |
| FAO-REF-01 | 83 | 83 | 83 | 10 | 10 | 10 |
| WEO-V1 | 181 | 206 | 246 | 26 | 30 | 44 |
| WEO-V2 | 192 | 258 | 376 | 26 | 33 | 48 |
| TAR-V1 | 327 | 437 | 446 | 58 | 85 | 112 |
| TAR-V3 | 238 | 272 | 262 | 46 | 59 | 61 |

Source: IIASA world food system simulations, May 2009.

## 7. IMPACTS OF FIRST-GENERATION BIOFUEL EXPANSION ON FOOD SYSTEM INDICATORS

This section presents the results of an integrated spatial ecological and economic assessment of the impacts of an accelerated expansion of biofuel production, evaluated in the context of the world food economy and global resource base.

The previous sections briefly presented the analysis framework used in this study and the key assumptions regarding economic development and transport energy demand, in particular use of first- and second-generation biofuels. Internally consistent sets of assumptions were formulated as model scenarios and used to quantify impacts of expanding biofuel use on agriculture and world food system outcomes. In total ten such scenarios were analyzed; the acronyms used and a brief description is given in Table 7.1.

**Table 7.1: Biofuel scenarios analyzed in this study**

| Scenario acronym | Scenario description |
|---|---|
| FAO-REF-00 | Starting in 1990, assumes a world without any agricultural crops used for biofuel production. |
| FAO-REF-01 | Assumes historical biofuel development until 2008; biofuels feedstock demand is kept constant after 2008; used as a reference simulation to which alternative biofuel scenarios are compared for their impact. |
| WEO-V1 | Assumes transport energy demand and regional biofuel use as projected by International Energy Agency (IEA) in its WEO 2008 Reference Scenario. Second-generation conversion technologies become commercially available after 2015; deployment is gradual (see Table 6.3) |
| WEO-V2 | Assumes transport energy demand and regional biofuel use as projected by IEA in its WEO 2008 Reference Scenario. Assumes that due to delayed arrival of second-generation conversion technologies all biofuel production until 2030 is based on first-generation feedstocks. |
| TAR-V1 | Assumes transport energy demand as projected by IEA in its WEO 2008 Reference Scenario. Assumes that mandatory, voluntary or indicative targets for biofuel use announced by major developed and developing countries will be implemented by 2020, resulting in about twice the biofuel consumption compared to WEO 2008. Second-generation conversion technologies become commercially available after 2015; deployment is gradual (percentage as in WEO-V1) |
| TAR-V3 | Assumes transport energy demand as projected by IEA in its WEO 2008 Reference Scenario. Assumes that mandatory, voluntary or indicative targets for biofuel use announced by major developed and developing countries will be implemented by 2020. Accelerated development of second-generation conversion technologies permits rapid deployment; 33% and 50% of biofuel use in developed countries from second-generation in 2020 and 2030 respectively. |
| SNS | Sensitivity scenarios assuming low (V1), intermediate (V2), high (V3), and very high (V4) share of first-generation biofuels in total transport fuels (see Table 6.4). |

The evaluation of the impacts of additional demand for first-generation biofuels on production, consumption, and trade of agricultural commodities, in particular on food staples, was carried out by comparing the results of a range of biofuel-expansion scenarios to a reference projection of the world food system simulated without imposing additional biofuel demand. Results of the reference projection were presented in section 3.

The analyzed biofuel-expansion scenarios involved several simulation experiments related to two aspects:

- Share of transport energy to be supplied from biofuels;
- Sensitivity of results to development speed of second-generation technologies.

As for the climate change analysis, all exogenous variables, such as population growth, technical progress and growth of the non-agricultural sector, were left at the levels specified in the reference projection. No specific adjustment policies to counteract altered performance of agriculture have been assumed beyond the farm-level adaptations resulting from economic adjustments of the individual actors in the national models. The adjustment processes taking place in the different scenarios are the outcome of the imposed additional biofuel demand causing changes of agricultural prices in the international and national markets; this in turn affects investment allocation and labor migration between sectors as well as reallocation of resources within agriculture. Time is an important aspect in this adjustment process.

### Agricultural prices

As is to be expected in a general equilibrium world food system model, when simulating scenarios with increased demand for food staples due to the production of first-generation biofuels, the resulting market imbalances at prevailing prices push international prices upwards.

**Table 7.2: Impacts of biofuel expansion scenarios on agricultural prices**

| Scenario | Change of Price Index relative to Reference scenario FAO-REF-01 (percent) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Cereals | | | Crops | | | Agriculture | | |
| | 2020 | 2030 | 2050 | 2020 | 2030 | 2050 | 2020 | 2030 | 2050 |
| WEO-V1 | 11 | 5 | 10 | 10 | 7 | 10 | 8 | 5 | 7 |
| WEO-V2 | 14 | 13 | 21 | 12 | 11 | 15 | 9 | 8 | 11 |
| TAR-V1 | 38 | 38 | 27 | 35 | 34 | 27 | 27 | 26 | 20 |
| TAR-V3 | 19 | 17 | 12 | 22 | 18 | 13 | 17 | 12 | 9 |
| SNS-V1 | 5 | 5 | 7 | 4 | 5 | 6 | 3 | 3 | 4 |
| SNS-V2 | 21 | 15 | 21 | 17 | 15 | 18 | 13 | 11 | 13 |
| SNS-V3 | 37 | 35 | 40 | 30 | 29 | 31 | 24 | 22 | 23 |
| SNS-V4 | 55 | 58 | 60 | 47 | 47 | 47 | 36 | 36 | 35 |

Source: IIASA world food system simulations; scenario FAO-REF-01, May 2009.

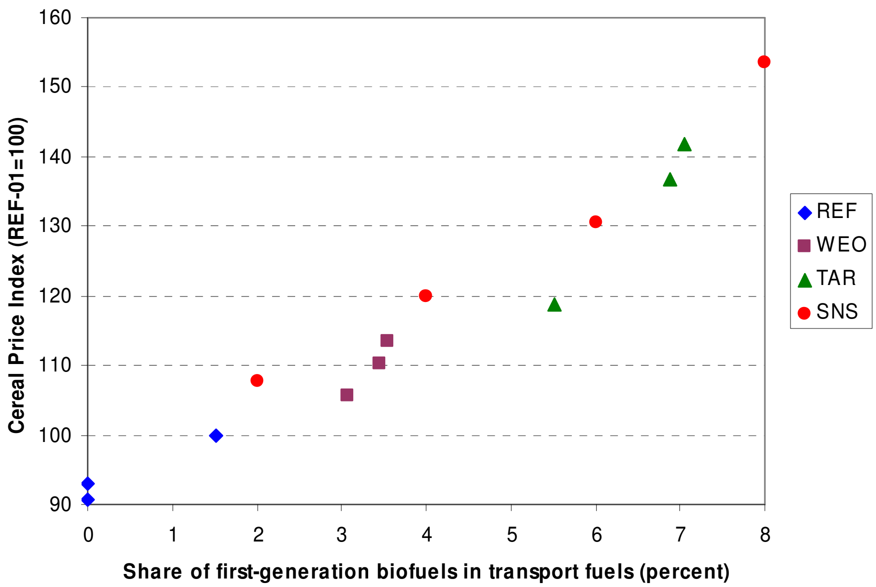
Table 7.2 shows the results for selected scenarios, namely biofuel demand according to WEO projections in scenario variants WEO-V1 and WEO-V2 (the latter assuming delayed introduction of second-generation technologies) and high biofuel consumption levels according to the TAR scenario in variants TAR-V1 and TAR-V3 (accelerated introduction of second-generation biofuels).

For 2020, the price increases for both cereals and other crops under the WEO scenario are in the order of 10 percent. As the contribution of second-generation biofuels is still small in WEO-V1, the further delay assumed in WEO-V2 causes only moderate further crop price increases. For biofuel demand specified in the TAR scenario (i.e. about twice the level projected in the WEO scenario) the impact on crop prices in 2020 is fairly substantial, of the order of 35 percent. With accelerated introduction of cellulosic ethanol, as assumed in TAR-V3, the price impact on cereals would be halved to about 19 percent.

For 2030 the pattern of price impacts remains similar to 2020. As second-generation biofuels gain importance towards 2030, the differences in price impacts between WEO-V1 and WEO-V2 variants become more visible. With accelerated deployment of second-generation fuels even the large volumes of biofuels produced in TAR-V3 can be achieved with price increases of only about 15 percent.

Summarizing over all scenario experiments, we find that agricultural prices considerably depend on the aggregate share that first-generation biofuels are mandated to contribute to total transport fuel consumption. This is shown in Figure 7.1.

**Figure 7.1: Cereal price index versus share of first-generation biofuels in transport fuels, in 2020**




Source: IIASA world food system simulations, May 2009.

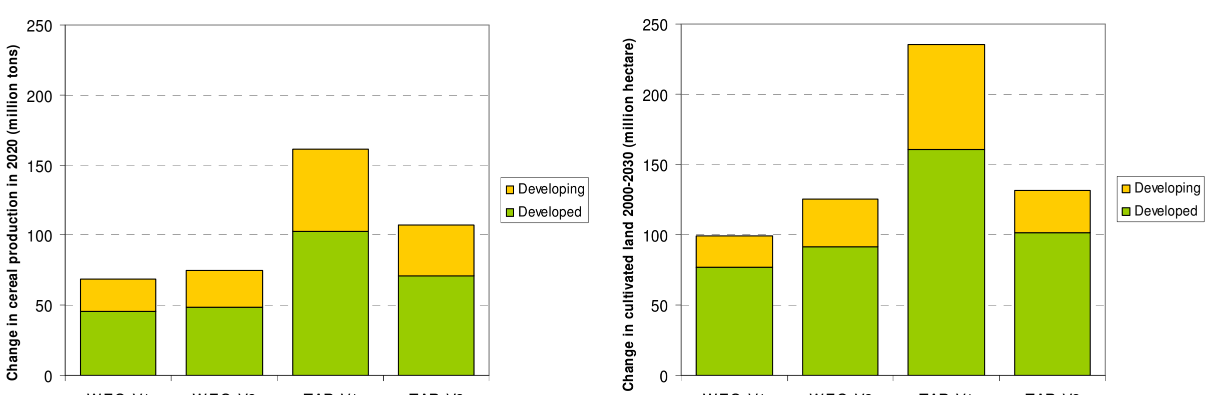
Note: SNS = sensitivity scenarios; TAR = scenario simulations based on mandates and indicative voluntary targets; WEO = simulations based on WEO 2008 projections of biofuel demand; REF = reference projections with constant, decreasing or no biofuel demand beyond 2008).

## Cereal demand and production

The rising agricultural prices in the biofuel scenarios provide incentives on the supply side, for intensifying production and for augmenting and reallocating land, capital and labor. At the same time, consumers react to price increases and adjust their patterns of consumption. Figure 7.2 shows the producer response of cereal sectors for different biofuel scenarios in 2020 and 2030, i.e. the amount of additional cereal production realized in each scenario compared to REF-01.

**Figure 7.2: Change in cereal production relative to baseline FAO-REF-01, in 2020**

a) in 2020 b) in 2030




Source: IIASA world food system simulations, May 2009.

**Table 7.3: Impacts of biofuel expansion scenarios on cereal production and demand**

| Scenario | Change of Cereal Production and Demand relative to Reference scenario FAO-REF-00 (million tons) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2020 | | | 2030 | | | 2050 | | |
| | Biofuel use | Produc-tion | Food/ feed | Biofuel use | Produc-tion | Food/ feed | Biofuel use | Produc-tion | Food/ feed |
| REF-01 | 83 | 64 | -19 | 83 | 66 | -17 | 83 | 68 | -15 |
| WEO-V1 | 181 | 134 | -46 | 206 | 167 | -45 | 246 | 180 | -62 |
| WEO-V2 | 192 | 140 | -48 | 258 | 194 | -68 | 376 | 271 | -102 |
| TAR-V1 | 327 | 229 | -96 | 437 | 308 | -133 | 446 | 313 | -127 |
| TAR-V3 | 238 | 174 | -59 | 272 | 201 | -69 | 262 | 198 | -62 |

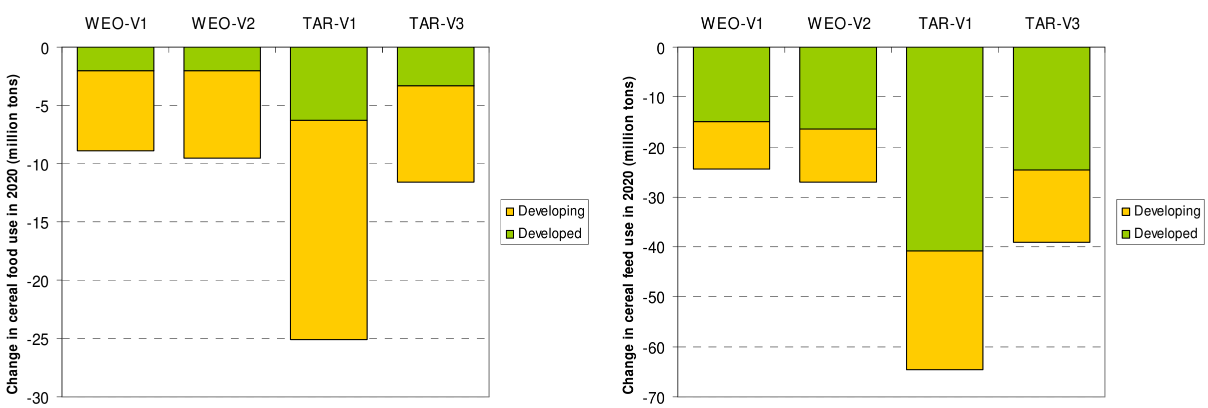
Source: IIASA world food system simulations; compared to reference scenario FAO-REF-00, May 2009.

In 2020, the additional (compared to 83 million tons representing 2008 levels) global use of cereal commodities for ethanol production relative to the reference simulation FAO-REF-01 is around 100 million tons in WEO-V1 and WEO-V2, 240 million tons in TAR-V1 and 155 million tons in scenario TAR-V3. Figure 7.2 highlights that production increases in response to higher agricultural prices are stronger in developed countries, as are the reductions in feed use (see Figure 7.3). When it comes to food use, however, consumption in developed countries is less responsive than in developing countries, which account for 75 percent of the 'forced' reduction in cereal food consumption. Rising food commodity prices tend to negatively affect lower income consumers more than higher income consumers. First, lower-income consumers spend a larger share of their income on food and second, staple food commodities such as corn, wheat, rice, and soybeans account for a larger share of their food expenditures. Responses on the consumer side, reduced food and feed use of cereals, are shown in Figure 7.3.

**Figure 7.3: Change of cereal use relative to baseline FAO-REF-01, in 2020**

a) Change in direct food use

b) Change in feed use

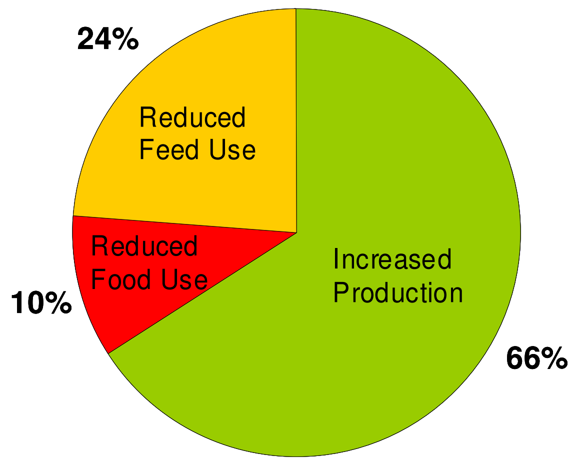



Source: IIASA world food system simulations; May 2009.

**Box 7.1: Where do the cereals needed for biofuel production come from?**

On average about two-thirds of the cereals used for ethanol production are obtained from additional crop production.

The remaining one-third comes from consumption changes. The reduction in direct cereal food consumption accounts for ten percent of the amount of cereals used for biofuel production, reduced feed use accounts for about a quarter.



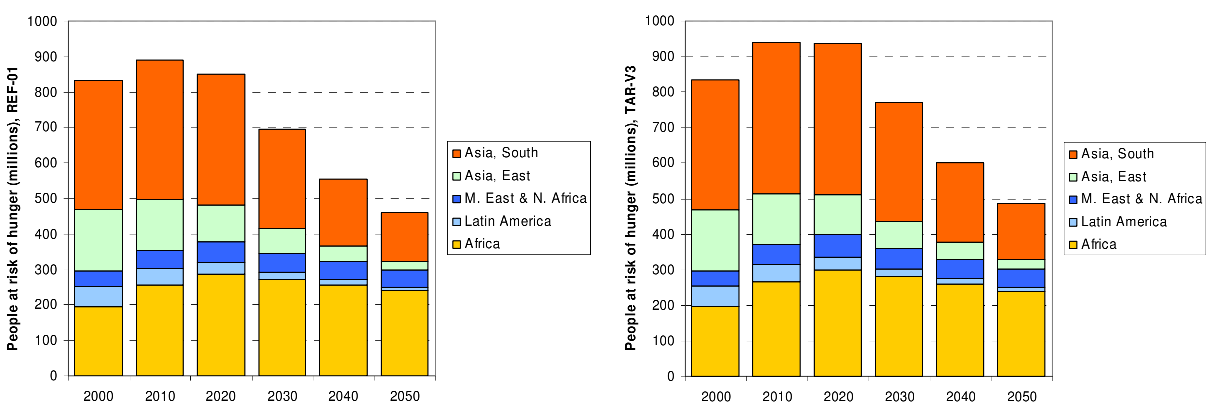

Source: IIASA world food system simulations; May 2009.

### Risk of hunger

The estimated number of people at risk of hunger used in the world food system model is based on FAO data (FAO, 2001; 2008b) and relies on a strong correlation between the share of undernourished in a country's total population and the ratio of average per capita dietary food supply relative to average national per capita food requirements.

**Figure 7.4: Risk of hunger in FAO-REF-01 and TAR-V3 scenarios, developing countries**

a) Scenario FAO-REF-01 b) Scenario TAR-V3




Source: IIASA world food system simulations; May 2009.

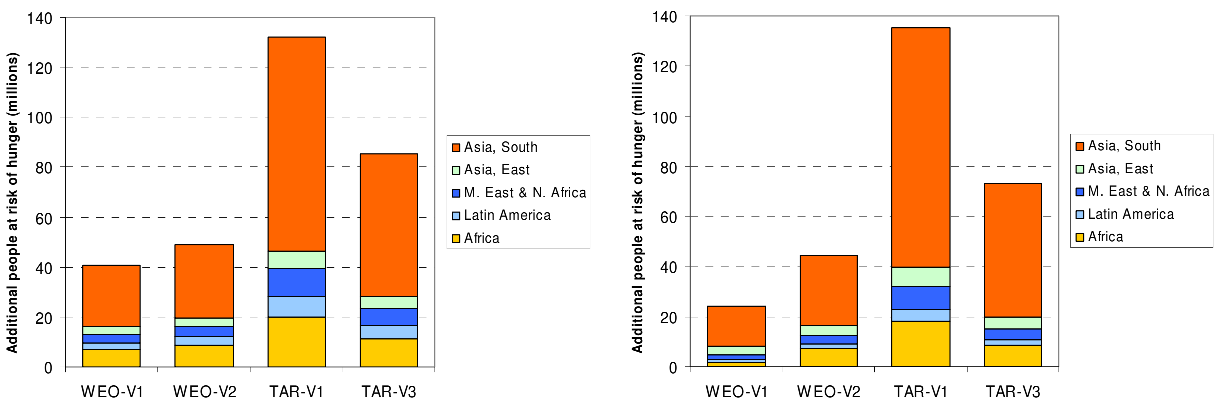
The model results show that an ambitious biofuel target for 2020, as specified in the TAR scenario, causes higher prices if achieved mainly by production of first-generation biofuels. Consequently this reduces food consumption in developing countries, which in turn in the simulations results in an increased number of people at risk of hunger. Figure 7.4 shows a comparison of results until 2050 for the baseline scenario FAO-REF-01 (no climate change and no additional biofuel demand after 2008) versus estimated number of people at risk of hunger in the TAR-V3 scenario, i.e. when implementing an ambitious global biofuel target with swift introduction of second-generation technologies.

While in the reference scenario FAO-REF-01 the number of undernourished people peaks in 2009/10 at somewhat more than 890 million and then declines (estimated 850 million in 2020, 700 million in 2030, and 460 million in 2050), this indicator stays at a high level in the TAR-V3 scenario until 2020 at about 940 million and only then starts to decline as second-generation production begins to take pressure off the competing food-feed-biofuel feedstock markets.

Figure 7.5 presents the simulated regional distribution of additional undernourished in different biofuel scenarios, showing a large impact in particular in South Asia. It is worth noting that even with relatively swift deployment of second-generation technologies, as assumed in scenario TAR-V3, the results for 2020 show an increase of 80 million undernourished people.

**Figure 7.5: Additional people at risk of hunger relative to baseline FAO-REF-01**

a) in 2020 b) in 2030




Source: IIASA world food system simulations; May 2009.

The reference scenario REF-01, keeping biofuels consumption constant after 2008, projects for developing countries the number of undernourished people in 2020 and 2030 at respectively 850 and 700 millions. The biofuels target scenario estimates for developing countries that an additional 132 and 136 million people will be at risk of hunger in 2020 and in 2030 respectively. In the biofuels target scenario, with accelerated second-generation biofuels deployment, the corresponding number of additional people at risk of hunger decreased to 85 million and 74 million respectively in 2020 and 2030. Africa and South Asia account for more than two-thirds of the additional population at risk of hunger in developing countries across biofuels scenarios in 2020 as well as in 2030.

## Value added of crop and livestock production

Biofuel development has been seen as a means to diversify agricultural production and – especially in developed economies – this has shaped agricultural support policies. This study has considered as to what extent the additional production of crops developed on arable land as feedstocks for biofuels production will increase value added in agriculture. The percentage changes relative to the reference scenario FAO-REF-00, without any biofuels, is shown in Table 7.4.

Table 7.4 highlights that for all biofuels scenarios agricultural value added increases at the global and regional levels, as indeed expected. For instance for scenario WEO-V1 (with relatively modest biofuels development), the changes in absolute terms amount to US1990$ 41 billion in 2020, 57 billion in 2030 and 71 billion in 2050. The developed countries account initially for about 50 percent of the global gains in agricultural value added. As the relative weight of developed countries in global agriculture decreases over time, so does their share in global gains of agricultural value added, amounting to about 50 percent in 2030, and on average 45 percent of the projected gains in 2050. Table 7.4 also shows that agricultural sectors in developed countries benefit relatively more than in developing countries in terms of percentage gains relative to the baseline. In scenario WEO-V1 the increase in 2020 relative to scenario REF-00 recorded for developed countries is 4.3 percent compared to only about 1.8 percent for developing countries. While Africa and Latin America achieve gains of 2.4 and 3.1 percent, the gains achieved for the Middle East & North Africa region and for Asian regions is only 0.9 to 1.9 percent.

**Table 7.4: Impacts of biofuel expansion scenarios on agricultural value added**

| Scenario | Change of Agricultural Value Added relative to Reference scenario FAO-REF-00 (percent) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | World | | | Developed countries | | | Developing countries | | |
| | 2020 | 2030 | 2050 | 2020 | 2030 | 2050 | 2020 | 2030 | 2050 |
| REF-00 | 1.2 | 1.2 | 0.9 | 2.4 | 2.9 | 2.0 | 0.8 | 0.7 | 0.6 |
| WEO-V1 | 2.5 | 3.1 | 3.2 | 4.3 | 6.3 | 5.8 | 1.8 | 1.9 | 2.4 |
| WEO-V2 | 2.5 | 3.5 | 4.0 | 4.4 | 7.4 | 7.8 | 1.8 | 2.1 | 2.9 |
| TAR-V1 | 4.4 | 6.6 | 7.1 | 6.9 | 12.1 | 11.4 | 3.4 | 4.4 | 5.7 |
| TAR-V3 | 3.7 | 4.9 | 4.5 | 5.7 | 8.9 | 7.3 | 2.9 | 3.3 | 3.7 |

Source: IIASA world food system simulations; reference scenario FAO-REF-00, May 2009.

**Table 7.5: Impacts of biofuel expansion scenarios on regional agricultural value added**

| Region | Change of Agricultural Value Added relative to Reference scenario FAO-REF-00 (percent) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Scenario WEO-V1 | | | Scenario WEO-V2 | | | Scenario TAR-V3 | | |
| | 2020 | 2030 | 2050 | 2020 | 2030 | 2050 | 2020 | 2030 | 2050 |
| North America | 8.5 | 11.2 | 8.6 | 8.7 | 13.2 | 12.8 | 11.6 | 14.1 | 8.6 |
| Europe & Russia | 1.8 | 3.5 | 4.6 | 1.7 | 4.1 | 5.3 | 1.9 | 6.1 | 7.3 |
| Pacific OECD | 0.8 | 1.6 | 1.7 | 0.8 | 1.4 | 1.6 | 1.7 | 3.0 | 2.8 |
| Africa, sub-Saharan | 2.4 | 2.4 | 2.9 | 2.4 | 2.6 | 3.4 | 4.2 | 4.8 | 4.5 |
| Latin America | 3.1 | 3.5 | 5.2 | 3.1 | 3.8 | 6.4 | 4.9 | 5.7 | 7.8 |
| Middle East & N. Africa | 1.9 | 2.1 | 2.7 | 2.0 | 2.2 | 2.9 | 3.4 | 3.9 | 3.6 |
| Asia, East | 0.9 | 1.1 | 1.2 | 0.9 | 1.2 | 1.4 | 1.3 | 1.5 | 1.7 |
| Asia, South/Southeast | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.5 | 2.6 | 2.8 | 2.3 |
| Rest of World | 1.2 | 1.2 | 1.1 | 1.3 | 1.4 | 0.5 | 2.6 | 3.0 | 2.4 |
| Developed | 4.3 | 6.3 | 5.8 | 4.4 | 7.4 | 7.8 | 5.7 | 8.9 | 7.3 |
| Developing | 1.8 | 1.9 | 2.4 | 1.8 | 2.1 | 2.9 | 2.9 | 3.3 | 3.7 |
| Rest of World | 1.2 | 1.2 | 1.1 | 1.3 | 1.4 | 0.5 | 2.6 | 3.0 | 2.4 |
| World | 2.5 | 3.1 | 3.2 | 2.5 | 3.5 | 4.0 | 3.7 | 4.9 | 4.5 |

Source: IIASA world food system simulations; reference scenario FAO-REF-00, May 2009.

In scenario TAR-V1, with a high demand for first-generation biofuels due to high national targets and only gradual introduction of second-generation technologies, crop and agriculture value added increases substantially, globally by some 6.6 percent by 2030. Global agricultural value added is higher by 73 billion US1990$ in 2020, 120 billion in 2030, and 155 billion in 2050. Again, the percentage gains in scenario TAR-V1 are higher for developed countries (about 6.9 percent in 2020) compared to developing regions (average 3.4 percent increase in 2020) where estimated gains fall in a range of 1.7 to 5.7 percent. The biofuels target scenario TAR-V1 estimates the increase in agriculture value added (measured in constant 1990 US$) as a result of biofuels development at US$ 33 billion and US$ 62 billion in the developed countries in 2020 and 2030 respectively. The corresponding values for the developing countries are US$ 37 billion and US$ 51 billion respectively.

### Impacts on the use of cultivated land

The discussion of the extent and kind of land required for biofuel production and of the impacts on cultivated land caused by expanding biofuel production, distinguishes two elements: first, direct land use changes, i.e. estimating the extent of land that is used for producing biofuel feedstocks; secondly, the estimation of indirect land use effects, which can result from bioenergy production displacing services or commodities (food, fodder, fiber products) on arable land currently in production.

The approach pursued in this study is to apply a general equilibrium framework that can capture both direct and indirect land use changes by modeling responses of consumers and producers to price changes induced by introducing competition with biofuel feedstock production. This approach accounts for land use changes but also considers production intensification on existing agricultural land as well as consumer responses to changing availability and prices of agricultural commodities.

In a baseline projection without any use of agricultural feedstocks for biofuel production, as portrayed in scenario FAO-REF-00, the expansion of arable land to meet growing food and feed requirements during 2000 to 2020 amounts to about 80 million hectares of additional land put into cultivation. Africa and Latin America, with a projected increase of cultivated land of respectively 39 million and 33 million hectares, account for more than 85 percent of total net arable land expansion.

**Table 7.6: Impacts of biofuel expansion scenarios on cultivated land use**

| Scenario | Change of Cultivated Land relative to Reference scenario FAO-REF-00 (percent) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | World | | | Developed countries | | | Developing countries | | |
| | 2020 | 2030 | 2050 | 2020 | 2030 | 2050 | 2020 | 2030 | 2050 |
| REF-00 | 8 | 8 | 5 | 3 | 3 | 1 | 5 | 5 | 4 |
| WEO-V1 | 19 | 19 | 21 | 6 | 6 | 5 | 12 | 13 | 16 |
| WEO-V2 | 20 | 23 | 29 | 6 | 8 | 7 | 13 | 15 | 21 |
| TAR-V1 | 38 | 46 | 48 | 12 | 14 | 11 | 24 | 30 | 36 |
| TAR-V3 | 29 | 30 | 29 | 9 | 9 | 6 | 19 | 20 | 22 |

Source: IIASA world food system simulations; reference scenario FAO-REF-00, May 2009.

Table 7.6, shows the *additional* use of cultivated land in 2020, 2030 and 2050 in comparison to a scenario without any crop-based biofuels. For the WEO and TAR biofuel scenarios shown this additional use of cultivated land in 2020 falls in the range of 19 million hectare (scenario WEO-V1) to 38 million hectares (scenario TAR-V1). For developed countries the arable land use increases in different biofuel scenarios during 2000-2020 in the range of 6 to 12 million hectares, compared to a net decrease by 3 million hectares in a scenario without biofuels. Developing countries record in the baseline without biofuels (scenario FAO-REF-00) an increase of arable land use during 2000-2020 that amounts to 87 million hectares; for comparison, additional crop demand due to biofuel development results in a total expansion of cultivated land use of 99 to 112 million hectares, and additional use of 12 to 24 million hectares. The difference of 24 million hectares arable land use in developing countries in scenario TAR-V1 (compared to the results without biofuel demand) is mainly explained by an additional expansion of 9 million hectares in sub-Saharan Africa and 11 million hectares in South America.

When looking at differences in expansion of cultivated land for the period 2000 to 2030, then the range of estimates for biofuel scenarios relative to the baseline (without biofuels) widens further, from an additional use of 19 million hectares (scenario WEO-V1) to 46 million hectares (scenario TAR-V1).

For the full range of simulated scenarios (including sensitivity scenarios) the use of cultivated land in 2020 goes from 1643 million hectares to 1691 million hectares, a difference of 48 million hectares. In 2030 it ranges from 1676 million hectares to 1734 million hectares, i.e. a maximum additional use of 58 million hectares.

**Table 7.7: Impacts of biofuel expansion scenarios on harvested area**

| Scenario | Change of Harvested Area relative to Reference scenario FAO-REF-00 (percent) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | World | | | Developed countries | | | Developing countries | | |
| | 2020 | 2030 | 2050 | 2020 | 2030 | 2050 | 2020 | 2030 | 2050 |
| REF-00 | 13 | 15 | 8 | 6 | 7 | 2 | 7 | 8 | 6 |
| WEO-V1 | 29 | 33 | 31 | 10 | 13 | 6 | 19 | 20 | 25 |
| WEO-V2 | 30 | 39 | 43 | 10 | 15 | 8 | 20 | 24 | 34 |
| TAR-V1 | 57 | 74 | 71 | 17 | 23 | 12 | 38 | 49 | 57 |
| TAR-V3 | 45 | 50 | 42 | 14 | 17 | 7 | 30 | 32 | 35 |

Source: IIASA world food system simulations; reference scenario FAO-REF-00, May 2009.

Increases of harvested area account for both the expansion of cultivated land as well as increased multi-cropping, i.e. the intensification of cropping in existing cultivated land. For the WEO and TAR biofuel scenarios this *additional* harvested area falls in the range of 26 million hectares (scenario WEO-V1) to 59 million hectares (scenario TAR-V1). In developed countries the harvested area increases in different biofuel scenarios by 10 to 18 million hectares, in developing by 17 to 35 million hectares. While Africa and South America accounted for more than 80 percent of physical land expansion (i.e. additional cultivated land) their combined share in additional harvested area is only about 45 percent, which indicates that higher agricultural prices lead to a substantial intensification of cropping also in regions with limited land resources.

In summary, while total global arable land use increases by only 1-3 percent in different biofuel scenarios compared to a situation without biofuels - a number that may seem small at first sight – the impact becomes substantial when expressed in terms of net cultivated land expansion during respectively 2000-2020, 2000-2030, and 2000-2050. From this perspective, the impact of biofuel scenarios is to increase the net expansion of cultivated land during 2000-2020 by 20-45 percent, by 15-40 percent over the period 2000-2030, and by 12-30 percent during 2000-2050.

## 8. SECOND-GENERATION BIOFUELS

The previous section has demonstrated that the concerns about expanding the use of first-generation biofuels, especially when derived from cereals and oilseeds, are well justified in view of their possible impacts on agricultural prices, food security, and land use.

In this situation, second-generation biofuels, produced from woody or herbaceous non-food plant materials as feedstocks, have attracted great attention in the hope that substantial technological and economic barriers, which still hamper a commercial deployment of second-generation technologies, can be resolved in the near future and that they will soon become fully commercialized.

Some of the problems associated with first-generation biofuels can be avoided by the production of biofuels manufactured from agricultural and forest residues and from non-food crop feedstocks. First, the energy yields per hectare achievable with second-generation feedstocks are generally higher than those of first-generation biofuels, and secondly different quality land could possibly be used for production, thus limiting or avoiding land use competition with food production as lignocellulosic feedstocks are expected to be mainly grown outside cultivated land.

Following substantial government grants recently made to develop second-generation feedstocks and conversion technologies, and based on the announced plans of companies developing second-generation biofuel facilities, an optimistic view is that first fully commercial-scale operations could possibly be seen as early as 2012. However, with the complexity of the technical and economic challenges involved, a more realistic expectation is that wide deployment of commercial plants is unlikely to begin before 2015 or 2020. Therefore it is still uncertain what contribution second-generation biofuels will make by 2030 to meeting the global transport fuel demand (IEA, 2008b).

Uncertainties have been included in the scenario analysis by simulating the outcomes for a range of assumptions on the expected share of biofuels that will be contributed by second-generation fuels (see Table 8.1).

**Table 8.1: Share and total amount of second-generation biofuels, by scenario**

| Scenario | Share of second-generation fuels in total transport biofuels (percent) | | | Use of second-generation biofuels (Mtoe) | | |
|---|---|---|---|---|---|---|
| | 2020 | 2030 | 2050 | 2020 | 2030 | 2050 |
| **Global average** | | | | | | |
| WEO-V1 | 3 | 13 | 30 | 3 | 17 | 62 |
| WEO-V2 | 0 | 0 | 10 | 0 | 0 | 21 |
| WEO-V3 | 13 | 30 | 49 | 13 | 38 | 103 |
| TAR-V1 | 2 | 12 | 26 | 5 | 37 | 110 |
| TAR-V2 | 0 | 0 | 10 | 0 | 0 | 42 |
| TAR-V3 | 22 | 38 | 55 | 41 | 113 | 234 |
| **Developed countries** | | | | | | |
| WEO-V1 | 4 | 19 | 40 | 3 | 15 | 50 |
| WEO-V2 | 0 | 0 | 10 | 0 | 0 | 12 |
| WEO-V3 | 18 | 36 | 59 | 11 | 29 | 73 |
| TAR-V1 | 4 | 18 | 39 | 5 | 32 | 84 |
| TAR-V2 | 0 | 0 | 10 | 0 | 0 | 21 |
| TAR-V3 | 33 | 51 | 68 | 39 | 91 | 146 |

Source: Fischer et al., 2009.

A recent report published by the IEA states that both principal conversion processes, the biogeochemical conversion of cellulose to ethanol and the thermo-chemical conversion to FT-diesel, can potentially convert 1 dry ton of biomass (with about 20 GJ/ton energy content) to around 6.5 GJ of energy carrier in the form of biofuels, i.e. an overall biomass to biofuel conversion efficiency of about 35 percent (IEA, 2008b). Ranges of indicative biofuel yields per dry ton of biomass are shown in Table 8.2.

**Table 8.2: Indicative biofuel yields of second-generation conversion technologies**

| | Biofuel yield (liters/dry ton) | | Energy content (MJ/liter) | Energy yield (GJ/dry ton) | | Biomass input (dry ton/toe) | |
|---|---|---|---|---|---|---|---|
| Process | Low | High | LHV | Low | High | Low | High |
| Biochemical enzymatic hydrolysis ethanol | 110 | 300 | 21.1 | 2.3 | 6.3 | 18.0 | 6.6 |
| Thermo-chemical FT-diesel | 75 | 200 | 34.4 | 2.6 | 6.9 | 16.2 | 6.1 |
| Syngas-to-ethanol | 120 | 160 | 21.1 | 2.5 | 3.4 | 16.5 | 12.4 |

Source: IEA (2008b)

Assuming that on average biochemical ethanol yields of 250 liters per dry ton biomass will be achievable in 2020 and 300 liters per dry ton in 2030, and respectively 160 liters per dry ton and 200 liters per dry tons will result from thermo-chemical Fischer-Tropsch diesel conversion, then for each ton oil equivalent of second-generation biofuels an average 7.7 dry tons biomass are needed in 2020 and 6.4 dry tons by 2030. A value of 6 dry tons per toe is assumed for 2050. This results in a biomass demand for second-generation biofuels as listed in Table 8.3.

**Table 8.3: Biomass demand for second-generation biofuels, by scenario**

| Scenario | Global biomass demand for second-generation biofuels (million dry tons) | | | Biomass demand for second-generation biofuels in developed countries (million dry tons) | | |
|---|---|---|---|---|---|---|
| | 2020 | 2030 | 2050 | 2020 | 2030 | 2050 |
| WEO-V1 | 19 | 106 | 370 | 19 | 95 | 300 |
| WEO-V2 | 0 | 0 | 125 | 0 | 0 | 74 |
| WEO-V3 | 97 | 240 | 615 | 87 | 186 | 440 |
| TAR-V1 | 35 | 234 | 660 | 35 | 207 | 500 |
| TAR-V2 | 0 | 0 | 254 | 0 | 0 | 128 |
| TAR-V3 | 315 | 725 | 1402 | 297 | 583 | 875 |

Source: Fischer et al., 2009.

Rapid deployment of second-generation conversion technologies after 2015 in order to meet the biofuel production of the target (TAR-V3) scenario in 2020 and 2030 would require some 315 million dry tons of biomass in 2020, increasing to 725 million dry tons in 2030. Of this about 300 million dry tons in 2020 and nearly 600 million dry tons would be required to meet demand in developed countries.

## Land required for second-generation biofuels

Low-cost crop and forest residues, wood process wastes, and the organic fraction of municipal solid wastes can all be used as lignocellulosic feedstocks. In some regions substantial volumes of these materials are available and may be used. In such cases, the production of biofuels requires well-designed logistical systems but no additional land is needed. In other regions, with limited residues and suitable wastes and where large and growing amounts of feedstocks are demanded, additional land will be needed for establishing plantations of perennial energy grasses or short rotation forest crops. Typical yields for the most important suitable feedstocks are summarized in Table 8.4.

**Table 8.4: Typical yields of second-generation biofuel feedstocks**[7]

| | Current yields (dry tons/hectare) | Expected yield by 2030 (dry tons/hectare) |
|---|---|---|
| Miscanthus | 10 | 20 |
| Switchgrass | 12 | 16 |
| Short rotation willow | 10 | 15 |
| Short rotation poplar | 9 | 13 |

Source: Worldwatch Institute (2007)

Taking an average typical yield of around 10 dry tons per hectare as possible and reasonable in 2020, then the biomass requirements listed in Table 8.3, a maximum of 315 million dry tons in 2020, implies that up to 32 million hectares of land would be needed if all biomass were to come from plantations. In reality the land requirement in 2020 will be much lower due to large amounts of cheap crop and forest residues available. In this early stage of second-generation biofuel development most of the biomass would be required in developed countries. By 2030, assuming that research as well as learning would increase average yields to about 15 dry tons per hectare (as suggested in Table 8.4), then an upper limit of land required for feedstock production would be 50 million hectares in the TAR-V3 scenario and less than 20 million hectares in both WEO-V3 and TAR-V1 scenarios.

[7] These yields refer to generally good land; under marginal conditions, yields can be substantially lower.

While conventional agricultural feedstocks currently used in first-generation biofuel production compete with food crops, second-generation lignocelluloses technologies promise substantial greenhouse gas savings and may permit tapping into land resources currently not or only extensively used. Acknowledging these significant advantages of second-generation lignocellulosic biofuel feedstocks over conventional agricultural feedstocks, we employed a detailed geographical resource database (Fischer et al., 2008) to estimate land potentially available for bioenergy production under a "food and environment first" paradigm, i.e. excluding land currently used for food and feed production as well as excluding forests.

In this estimation, based on a 5′ by 5′ latitude/longitude grid (i.e. about 10 km by 10 km at the equator), we started from total land area and subtracted all land indicated as artificial and built up surfaces, all cultivated land and current forest land. In a next step all areas indicated or designated as legally protected were excluded. Then land was excluded with very low productivity, either due to cold temperatures in the high latitudes or high altitudes, or because of low annual precipitation, as well as land unsuitable because of steep sloping conditions.

Excluding from a total global land area of 13.2 billion hectares (excl. Antarctica and Greenland) all current cultivated land, forests, built-up land, water and non-vegetated land (desert, rocks, etc.) resulted in 4.6 billion hectares remaining land area (ca. 35 percent of total). Excluding from these extents the unproductive, very low productive (e.g. tundra, arid land) or steeply sloped land, a remaining area of 1.75 billion hectares (see Table 8.5) was estimated, which comprises of grassland and woodland.

**Table 8.5: Regional balance of land classified as unprotected grassland and woodland potentially useable for rain-fed lignocellulosic biofuel feedstock production**

| Region | Total grassland and woodland (mill. ha) | Of which | | | Potential rain-fed yield | | |
|---|---|---|---|---|---|---|---|
| | | Protected areas (mill. ha) | Unproductive or very low productive (mill. ha) | Balance of grassland and woodland (mill. ha) | Average yield (dry t/ha) | Low yield (dry t/ha) | High yield (dry t/ha) |
| North America | 659 | 103 | 391 | 165 | 9.3 | 6.7 | 21.4 |
| Europe & Russia | 902 | 76 | 618 | 208 | 7.7 | 6.9 | 14.5 |
| Pacific OECD | 515 | 7 | 332 | 175 | 9.8 | 6.5 | 20.0 |
| Africa | 1086 | 146 | 386 | 554 | 13.9 | 6.7 | 21.1 |
| Asia, East | 379 | 66 | 254 | 60 | 8.9 | 6.4 | 19.0 |
| Asia, South | 177 | 26 | 81 | 71 | 16.7 | 7.6 | 21.5 |
| Latin America | 765 | 54 | 211 | 500 | 15.6 | 7.1 | 21.8 |
| Middle East & N. Africa | 107 | 2 | 93 | 12 | 6.9 | 6.3 | 10.6 |
| Developed | 2076 | 186 | 1342 | 548 | 8.9 | 6.7 | 21.0 |
| Developing | 2530 | 295 | 1029 | 1206 | 14.5 | 6.8 | 21.5 |
| World | 4605 | 481 | 2371 | 1754 | 12.5 | 6.8 | 21.5 |

Source: Fischer et al., 2008.

Over two-thirds of this grassland and woodland potentially suitable for biofuels feedstock production is located in developing countries, foremost in Africa and South America (see Table 8.5). These estimates are to be understood as indicative only and are subject to the limitations and accuracy of global land cover, soil and terrain data.

An important current use of these land resources is livestock grazing. Using available UN FAOSTAT data on feed utilization of crops and processed crop products (e.g. oilseed cakes and meals), production of fodder crops, national livestock numbers and livestock production, we estimated the feed energy provided by these recorded sources in each country in order to determine the energy gap to be filled by grassland and pastures. The results of detailed livestock feed energy balances suggest that in year 2000 about 55-60 percent of the available grassland biomass globally was required for animal feeding. This share is about 40 percent in developed countries. It amounts to an average 65 percent for developing countries, with values for Asian regions larger than 80 percent and about 50 percent in sub-Saharan Africa.

Hence, at current use levels, the land potentially available for bioenergy production (assuming unbiased distribution between livestock feeding and bioenergy uses) was estimated in the order of 700 – 800 million hectares, characterized by a rather wide range of productivity levels. Of these extents an estimated 330 million hectares are in the developed countries (about one-third each in North America, Europe & Russia & Central Asian republics, and Pacific OECD). About 450 million hectares of this land were estimated for the developing countries; 275 million hectares in Africa and 160 million hectares in Latin America. Some regional details of the estimated land areas and potential yields of second-generation lignocellulosic feedstocks are presented in Table 8.5.

We have subtracted only the demand for livestock feeding as the main current alternative use. No allowances were included for other social or environmental functions of the land, e.g. as feed source for wildlife. Also, estimates are subject to uncertainties regarding grass and pasture yields, which due to scarcity of measured data had to be estimated in model simulations with the IIASA/FAO GAEZ model (Fischer et al., 2008).

It can be concluded that land demand for producing second-generation feedstocks as required for the most demanding TAR-V3 scenario in 2020 (about 30 million hectares) and in 2030 (about 50 million hectares) could be met without having to compete for cultivated land. The results of the biofuels target scenario with accelerated second-generation biofuels deployment indicate that production of lignocellulosic feedstocks on some 100 million hectares would be sufficient to achieve the biofuels target share in world transport fuels in 2050.

However, there is still a need to carefully assess and respect the current uses and functions of potentially suitable land, to regulate land use in an integrated approach across sectors to achieve land use efficiency, avoid conflicts and to protect the rights of the weakest members of society when land ownership is uncertain. Another major challenge is development of the massive infrastructure and logistical systems required for second-generation feedstock supply systems.

## 9. COMBINED IMPACTS OF CLIMATE CHANGE AND EXPANSION OF BIOFUEL PRODUCTION ON WORLD FOOD SYSTEM INDICATORS

The previous sections reviewed the individual impacts of respectively climate change and the expansion of biofuel production on world food system indicators. Here the results for the combined impacts of both factors are summarized by comparing scenario outcomes with a reference simulation assuming current climate conditions and no use of crops for transport biofuel production.

### Agricultural prices

Table 9.1 presents the results of scenario analysis and lists deviations of price indexes for cereals, all crops, and for agriculture (all crop and livestock sectors) for a selection of scenarios constructed by combining different climate change projections and assumptions concerning $CO_2$ fertilization with a range of biofuel expansion scenarios.

Comparing these results with outcomes listed in earlier Table 5.1 (climate change impacts) and Table 7.2 (biofuel expansion impacts) indicates that the effects of both factors will combine to increase agricultural prices. For very next decades to come the more important scenario factor in determining price increases is the scale of crops used as biofuel feedstocks. In the medium- and long-term, climate change becomes the overriding factor.

Taking effects of $CO_2$ fertilization on crop yields into account, the simulated cereal price increases for the presented scenario combinations up to 2050 fall in the range of 15-40 percent when using the HadCM3 climate model outputs and are somewhat higher when applying climate scenarios based on the CSIRO GCM. Without $CO_2$ fertilization effects, the cereal price increases for the decades up to 2050 fall in the range of 20-55 percent. Simulated results for the 2080s, when climate change impacts seriously affect crop yields, the calculated cereal price increases are respectively in the range of 40-60 percent (with $CO_2$ fertilization) and 70-90 percent (without $CO_2$ fertilization).

**Table 9.1: Combined impact of climate change and biofuel expansion scenarios on agricultural prices**

| Scenario | $CO_2$ fertilization | Change of Price Index relative to Reference Climate (percent) | | | |
|---|---|---|---|---|---|
| | | 2020 | 2030 | 2050 | 2080 |
| **Cereals** | | | | | |
| Hadley A2, REF-01 | with | 4 | 5 | 5 | 28 |
| Hadley A2, WEO-V1 | with | 15 | 13 | 16 | 42 |
| Hadley A2, WEO-V2 | with | 18 | 18 | 26 | 49 |
| Hadley A2, TAR-V1 | with | 42 | 41 | 36 | 61 |
| Hadley A2, TAR-V3 | with | 23 | 20 | 16 | 43 |
| CSIRO A2, REF-01 | with | 9 | 10 | 10 | 28 |
| CSIRO A2, WEO-V1 | with | 22 | 17 | 20 | 43 |
| CSIRO A2, WEO-V2 | with | 24 | 23 | 30 | 49 |
| CSIRO A2, TAR-V1 | with | 49 | 49 | 40 | 61 |
| CSIRO A2, TAR-V3 | with | 29 | 26 | 20 | 45 |
| Hadley A2, REF-01 | without | 10 | 13 | 16 | 52 |
| Hadley A2, WEO-V1 | without | 20 | 21 | 30 | 68 |
| Hadley A2, WEO-V2 | without | 24 | 26 | 42 | 79 |
| Hadley A2, TAR-V1 | without | 49 | 54 | 53 | 87 |
| Hadley A2, TAR-V3 | without | 25 | 29 | 31 | 70 |
| **Crops** | | | | | |
| Hadley A2, REF-01 | with | 2 | 3 | 2 | 15 |
| Hadley A2, WEO-V1 | with | 13 | 11 | 12 | 25 |
| Hadley A2, WEO-V2 | with | 14 | 13 | 17 | 28 |
| Hadley A2, TAR-V1 | with | 36 | 35 | 31 | 41 |
| Hadley A2, TAR-V3 | with | 24 | 19 | 15 | 28 |
| CSIRO A2, REF-01 | with | 6 | 6 | 5 | 14 |
| CSIRO A2, WEO-V1 | with | 17 | 13 | 15 | 24 |
| CSIRO A2, WEO-V2 | with | 18 | 16 | 20 | 27 |
| CSIRO A2, TAR-V1 | with | 42 | 40 | 34 | 40 |
| CSIRO A2, TAR-V3 | with | 28 | 23 | 18 | 27 |
| Hadley A2, REF-01 | without | 7 | 9 | 12 | 33 |
| Hadley A2, WEO-V1 | without | 17 | 18 | 24 | 44 |
| Hadley A2, WEO-V2 | without | 19 | 20 | 30 | 48 |
| Hadley A2, TAR-V1 | without | 44 | 45 | 45 | 61 |
| Hadley A2, TAR-V3 | without | 28 | 28 | 27 | 48 |
| **Agriculture** | | | | | |
| Hadley A2, REF-01 | with | 1 | 2 | 1 | 11 |
| Hadley A2, WEO-V1 | with | 9 | 7 | 8 | 17 |
| Hadley A2, WEO-V2 | with | 10 | 9 | 12 | 19 |
| Hadley A2, TAR-V1 | with | 27 | 25 | 22 | 27 |
| Hadley A2, TAR-V3 | with | 17 | 13 | 10 | 19 |
| CSIRO A2, REF-01 | with | 4 | 4 | 4 | 10 |
| CSIRO A2, WEO-V1 | with | 13 | 9 | 11 | 17 |
| CSIRO A2, WEO-V2 | with | 13 | 12 | 15 | 19 |
| CSIRO A2, TAR-V1 | with | 32 | 30 | 24 | 27 |
| CSIRO A2, TAR-V3 | with | 21 | 17 | 12 | 18 |
| Hadley A2, REF-01 | without | 5 | 7 | 9 | 23 |
| Hadley A2, WEO-V1 | without | 13 | 13 | 17 | 31 |
| Hadley A2, WEO-V2 | without | 14 | 15 | 22 | 34 |
| Hadley A2, TAR-V1 | without | 33 | 33 | 33 | 42 |
| Hadley A2, TAR-V3 | without | 20 | 20 | 19 | 33 |

Source: IIASA world food system simulations; reference scenario FAO-REF-00, May 2009.

## Cereal production and consumption

Table 9.2 lists the scenario results with respect to production increases relative to the baseline scenario REF-00 (without climate change and no crop use for biofuel production).

**Table 9.2: Combined impact of climate change and biofuel expansion scenarios on production of cereals**

| Scenario | $CO_2$ fertilization | Change of cereal production relative to production in reference scenario FAO-REF-00 (million tons) | | | |
|---|---|---|---|---|---|
| | | 2020 | 2030 | 2050 | 2080 |
| **Production** | | | | | |
| Hadley A2, REF-01 | with | 70 | 65 | 54 | -26 |
| Hadley A2, WEO-V1 | with | 148 | 160 | 184 | 122 |
| Hadley A2, WEO-V2 | with | 149 | 197 | 273 | 219 |
| Hadley A2, TAR-V1 | with | 237 | 320 | 311 | 278 |
| Hadley A2, TAR-V3 | with | 181 | 209 | 198 | 142 |
| CSIRO A2, REF-01 | with | 55 | 48 | 31 | -16 |
| CSIRO A2, WEO-V1 | with | 126 | 146 | 161 | 126 |
| CSIRO A2, WEO-V2 | with | 133 | 180 | 250 | 228 |
| CSIRO A2, TAR-V1 | with | 222 | 299 | 291 | 291 |
| CSIRO A2, TAR-V3 | with | 165 | 190 | 177 | 151 |
| Hadley A2, REF-01 | without | 56 | 45 | 16 | -98 |
| Hadley A2, WEO-V1 | without | 135 | 138 | 139 | 41 |
| Hadley A2, WEO-V2 | without | 137 | 176 | 224 | 144 |
| Hadley A2, TAR-V1 | without | 223 | 294 | 266 | 193 |
| Hadley A2, TAR-V3 | without | 179 | 183 | 153 | 66 |

Source: IIASA world food system simulations; reference scenario FAO-REF-00, May 2009.

**Table 9.3: Combined impact of climate change and biofuel expansion scenarios on consumption (excl. biofuel use) of cereals**

| Scenario | $CO_2$ fertilization | Change of cereal consumption (excluding biofuel feedstocks) relative to reference scenario FAO-REF-00 (million tons) | | | |
|---|---|---|---|---|---|
| | | 2020 | 2030 | 2050 | 2080 |
| **Consumption** | | | | | |
| Hadley A2, REF-01 | with | -10 | -21 | -25 | -100 |
| Hadley A2, WEO-V1 | with | -33 | -47 | -60 | -117 |
| Hadley A2, WEO-V2 | with | -43 | -63 | -99 | -144 |
| Hadley A2, TAR-V1 | with | -88 | -122 | -128 | -156 |
| Hadley A2, TAR-V3 | with | -53 | -65 | -61 | -111 |
| CSIRO A2, REF-01 | with | -24 | -38 | -43 | -92 |
| CSIRO A2, WEO-V1 | with | -51 | -60 | -78 | -111 |
| CSIRO A2, WEO-V2 | with | -57 | -78 | -118 | -133 |
| CSIRO A2, TAR-V1 | with | -102 | -142 | -149 | -144 |
| CSIRO A2, TAR-V3 | with | -66 | -83 | -80 | -104 |
| Hadley A2, REF-01 | without | -24 | -41 | -63 | -170 |
| Hadley A2, WEO-V1 | without | -49 | -68 | -104 | -191 |
| Hadley A2, WEO-V2 | without | -57 | -82 | -144 | -221 |
| Hadley A2, TAR-V1 | without | -102 | -148 | -174 | -232 |
| Hadley A2, TAR-V3 | without | -60 | -86 | -105 | -183 |

Source: IIASA world food system simulations; reference scenario FAO-REF-00, May 2009.

Comparing these scenario results with the information in Table 7.3 (impact of biofuel expansion scenarios) indicates that there is up to 2050 relatively little impact of climate change on aggregate cereal supply and consumption for the HadCM3 scenario with CO2 fertilization; with CSIRO GCM derived climate change impacts the shortfall in consumption increases by about 20 million tons compared to biofuels only. Without CO2 fertilization effect on crop yields, the decrease in consumption for HadCM3 in 2030 is 68-148 million tons of which about 25 million tons is due to climate change. In 2050 the consumption reduction is in the range of 104-174 million tons of which about 50 million tons is caused by climate change. In the long-term, i.e. results for the 2080s, climate change accounts for up to two-thirds of the reduction in cereal consumption in scenarios with CO2 fertilization and for up to 85 percent in the HadCM3 scenario without CO2 fertilization.

### Risk of hunger

Combined scenario results regarding the indicator of number of people at risk of hunger are shown in Table 9.4. Results are consistent with the previous discussion on price changes and cereal consumption impacts. Note again that the conditions portrayed by the FAO Agriculture Toward 2030/50 reference projections imply a vast improvement in reducing undernourishment. Therefore relative changes compared to baseline REF-00 are large in 2050s and 2080s but relative small in absolute terms.

**Table 9.4: Combined impact of climate change and biofuel expansion scenarios on risk of hunger indicator**

| Scenario | $CO_2$ fertilization | Change of estimated number of people at risk of hunger relative to reference scenario FAO-REF-00 (millions) | | | |
|---|---|---|---|---|---|
| | | 2020 | 2030 | 2050 | 2080 |
| Hadley A2, REF-01 | with | 6 | 9 | 2 | 29 |
| Hadley A2, WEO-V1 | with | 51 | 41 | 34 | 39 |
| Hadley A2, WEO-V2 | with | 59 | 54 | 54 | 43 |
| Hadley A2, TAR-V1 | with | 150 | 148 | 99 | 55 |
| Hadley A2, TAR-V3 | with | 100 | 82 | 39 | 40 |
| CSIRO A2, REF-01 | with | 14 | 23 | 4 | 21 |
| CSIRO A2, WEO-V1 | with | 14 | 23 | 4 | 32 |
| CSIRO A2, WEO-V2 | with | 82 | 75 | 60 | 35 |
| CSIRO A2, TAR-V1 | with | 178 | 176 | 104 | 48 |
| CSIRO A2, TAR-V3 | with | 123 | 108 | 46 | 32 |
| Hadley A2, REF-01 | without | 33 | 43 | 41 | 58 |
| Hadley A2, WEO-V1 | without | 75 | 76 | 78 | 70 |
| Hadley A2, WEO-V2 | without | 85 | 88 | 102 | 77 |
| Hadley A2, TAR-V1 | without | 179 | 192 | 153 | 87 |
| Hadley A2, TAR-V3 | without | 117 | 119 | 88 | 72 |

Source: IIASA world food system simulations; reference scenario FAO-REF-00, May 2009.

### Cultivated land

Finally, Table 9.5 and Table 9.6 present the combined impact of climate change and biofuel expansion scenarios on cultivated land use. Summarizing over all scenarios shown in Table 9.5, the additional use of cultivated land in 2020 falls in the range of 16-40 million hectares, 17-49 million hectares in 2030, and 20-58 million hectares in 2050.

**Table 9.5: Combined impact of climate change and biofuel expansion scenarios on use of cultivated land**

| Scenario | $CO_2$ fertilization | Change of cultivated land relative to reference scenario FAO-REF-00 (million hectares) | | | |
|---|---|---|---|---|---|
| | | 2020 | 2030 | 2050 | 2080 |
| Hadley A2, REF-01 | with | 4 | 5 | 3 | 16 |
| Hadley A2, WEO-V1 | with | 16 | 17 | 20 | 33 |
| Hadley A2, WEO-V2 | with | 17 | 20 | 26 | 39 |
| Hadley A2, TAR-V1 | with | 35 | 43 | 47 | 59 |
| Hadley A2, TAR-V3 | with | 26 | 27 | 27 | 39 |
| CSIRO A2, REF-01 | with | 8 | 11 | 10 | 20 |
| CSIRO A2, WEO-V1 | with | 20 | 21 | 26 | 37 |
| CSIRO A2, WEO-V2 | with | 21 | 25 | 33 | 43 |
| CSIRO A2, TAR-V1 | with | 40 | 48 | 53 | 63 |
| CSIRO A2, TAR-V3 | with | 30 | 33 | 33 | 44 |
| Hadley A2, REF-01 | without | 8 | 12 | 14 | 33 |
| Hadley A2, WEO-V1 | without | 19 | 22 | 31 | 50 |
| Hadley A2, WEO-V2 | without | 20 | 25 | 37 | 56 |
| Hadley A2, TAR-V1 | without | 39 | 49 | 58 | 75 |
| Hadley A2, TAR-V3 | without | 29 | 33 | 38 | 57 |

Source: IIASA world food system simulations; reference scenario FAO-REF-00, May 2009.

For harvested area, as shown in Table 9.6, the additional use in 2020 falls in the range of 24-59 million hectares, 28-78 million hectares in 2030, and 28-85 million hectares in 2050.

**Table 9.6: Combined impact of climate change and biofuel expansion scenarios on harvested area**

| Scenario | $CO_2$ fertilization | Change of harvested area relative to reference scenario FAO-REF-00 (million hectares) | | | |
|---|---|---|---|---|---|
| | | 2020 | 2030 | 2050 | 2080 |
| Hadley A2, REF-01 | with | 7 | 9 | 3 | 22 |
| Hadley A2, WEO-V1 | with | 24 | 28 | 28 | 47 |
| Hadley A2, WEO-V2 | with | 25 | 33 | 38 | 56 |
| Hadley A2, TAR-V1 | with | 51 | 68 | 67 | 86 |
| Hadley A2, TAR-V3 | with | 39 | 45 | 38 | 56 |
| CSIRO A2, REF-01 | with | 13 | 17 | 11 | 24 |
| CSIRO A2, WEO-V1 | with | 30 | 36 | 34 | 50 |
| CSIRO A2, WEO-V2 | with | 31 | 41 | 45 | 58 |
| CSIRO A2, TAR-V1 | with | 58 | 75 | 74 | 89 |
| CSIRO A2, TAR-V3 | with | 46 | 52 | 45 | 60 |
| Hadley A2, REF-01 | without | 14 | 19 | 20 | 49 |
| Hadley A2, WEO-V1 | without | 30 | 38 | 46 | 75 |
| Hadley A2, WEO-V2 | without | 32 | 43 | 56 | 84 |
| Hadley A2, TAR-V1 | without | 59 | 78 | 85 | 112 |
| Hadley A2, TAR-V3 | without | 45 | 55 | 56 | 85 |

Source: IIASA world food system simulations; reference scenario FAO-REF-00, May 2009.

## 10. CONCLUSIONS

This paper reports on a large number of scenario experiments conducted to better understand how climate change and expanding bioenergy use may alter the long-term outlook for food, agriculture and resource availability.

IIASA's global and spatial agro-ecological and socio-economic assessment framework provided the analytical means and science-based knowledge for the assessment. Main conclusions and implications derived from the global quantitative analysis are summarized below.

- At the global aggregate level, climate change projected by different GCMs causes only modest changes to world food system indicators (prices, cereal production, food consumption, cultivated land use) in the period up to 2050.
- These findings assume full agronomic adaptation by farmers and do not take into account climate variability, which is expected to increase over the coming decades and may be an important destabilizing factor in the short- to medium-term.
- The capacity to adapt to climate change impacts is strongly linked to future development paths. The socioeconomic and, even more so, the technological characteristics of different development futures strongly affect the capability of societies to adapt to and mitigate climate change.
- Assumptions regarding yield increases due to increased atmospheric $CO_2$ concentrations (the so-called $CO_2$ fertilization effect) play an important role in scenario outcomes. When disregarding the $CO_2$ fertilization effect, negative climate change impacts on crop yields and world food system indicators are noticeable already in the short term and are very substantial in the medium and long-term.
- Scenario results confirm that, with and without $CO_2$ fertilization, the impacts of climate change on crop yields and production could become severe in the second half of this century.
- If expansion of biofuel production continues to rely mainly on agricultural crops and when expansion follows the pace projected by the IEA in 2008, or achieves levels implied by the mandates and targets set in many countries, this additional non-food use of crops will have a significant impact on the world food system.
- While biofuels could have an especially large impact in the period up to 2030, the aggregate impact on the food system is likely to reduce over time. The opposite is to be expected for climate change impacts.
- For the range of scenarios analyzed in this assessment, the combined impact of climate change and biofuel expansion on aggregate crop prices is in the range of a 10-45 percent increase. Decrease of cereal consumption typically falls within 35-100 million tons initially, increasing to a range of 60-150 million tons by 2050. In terms of cultivated land, an additional use in the range of 20-50 million hectares by 2030 and of 25-60 million hectares in 2050 can be expected.

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## ANNEX 1: THE MODELING FRAMEWORK

The study is based on a state-of-the-art ecological-economic modeling approach. The scenario-based quantified findings of the study rely on a modeling framework which includes as components, the FAO/IIASA Agro-ecological Zone model (AEZ) and the IIASA world food system model (WFS). The modeling framework encompasses climate scenarios, agro-ecological zoning information, demographic and socio-economic drivers, as well as production, consumption and world food trade dynamics.

### AEZ methodology

The AEZ modeling uses detailed agronomic-based knowledge to simulate land resources availability, assess farm-level management options and estimate crop production potentials. It employs detailed spatial biophysical and socio-economic datasets to distribute its computations at fine gridded intervals over the entire globe (Fischer et al., 2002a; 2005). This land-resources inventory is used to assess, for specified management conditions and levels of inputs, the suitability of crops in relation to both rain-fed and irrigated conditions, and to quantify expected attainable production of cropping activities relevant to specific agro-ecological contexts. The characterization of land resources includes components of climate, soils, landform, and present land cover. Crop modeling and environmental matching procedures are used to identify crop-specific environmental limitations, under various levels of inputs and management conditions.

In summary, the AEZ framework contains the following basic elements:

- Land resources database, containing geo-referenced climate, soil and terrain data;
- Land Utilization Types (LUT) database of agricultural production systems, describing crop-specific environmental requirements and adaptability characteristics, including input level and management.
- Mathematical procedures for matching crop LUT requirements with agro-ecological zones data and estimating potentially attainable crop yields, by land unit and grid-cell (AEZ global assessment includes 2.2 million land grid cells at 5′ by 5′ latitude/longitude);
- Assessments of crop suitability and land productivity;
- Applications for agricultural development planning.

### World food system model

The world food system model comprises a series of national and regional agricultural economic models. It provides a framework for analyzing the world food system, viewing national food and agricultural components as embedded in national economies, which in turn interact with each other at the international trade level. The model consists of 34 national and regional geographical components covering the world. The individual national/regional models are linked together by means of a world market, where international clearing prices are computed to equalize global demand with supply (see Box 1).

Simulations with the world food system model generate a variety of outputs. At the global level these include world market prices, global population, global production and consumption. At the country level it includes producer and retail prices, levels of production, use of primary production factors (land, labor, and capital), intermediate input use (feed and fertilizer), human consumption, use for biofuel production, and commodity trade, value added in agriculture, investment by sector and income by group and/or sector.

Population growth and technology are key external inputs to the model system. Population numbers and projected incomes are used to determine demand for food for the period of study. Technology affects yield estimates, by modifying the efficiency of production per given units of inputs and land. For simulations of historical periods up to the present, population data are taken from official U.N. data at country-level, while the rate of technical progress has been estimated from past agricultural performance.

To assess agricultural development over the next decades to 2050, it was necessary to first make some coherent assumptions about how key socio-economic drivers of food systems might evolve over that period. For the analysis reported in this paper, population projections were taken from the database of the UN World Population Prospects: The 2008 Revision (United Nations, 2009). Economic growth of countries and regional groups in the world food system model was calibrated based on information provided by the Agriculture Toward 2030/50 study group at FAO (J. Bruinsma, 2009; pers. communication).

Another external input to the model system is projected climate change, which affects region-specific crop suitability and attainable yields. This spatial agronomic information (derived from AEZ) is used in an aggregate form by the economic model as an input in allocating land and agricultural inputs (Fischer et al., 2005). In this study results of the coupled atmosphere-ocean GCM developed by the UK Hadley Center for Climate Prediction and Research and the Australian CSIRO were used to take into account climate change impacts on land suitability and productivity (Fischer et al., 2002b).

Box 1: **How does the world food system work?**

The world food system model is an applied general equilibrium (AGE) model system. While focusing on agriculture, this necessitates that also all other economic activities are represented in the model. Financial flows as well as commodity flows within a country and at the international level are kept consistent in the sense that they must balance, by imposing a system of budget constraints and market-clearing conditions. Whatever is produced will be demanded, either for human consumption, feed, biofuel use, or as intermediate input. Alternatively, commodities can be exported or put into storage. Consistency of financial flows is imposed at the level of the economic agents in the model (individual income groups, governments, etc.), at the national as well as the international level. This implies that total expenditures cannot exceed total income from economic activities and from abroad, in the form of financial transfers, minus savings. On a global scale, not more can be spent than what is earned.

Each individual model component focuses primarily on the agricultural sector, but includes also a simple representation the entire economy as necessary to capture essential dynamics among capital, labor and land. For the purpose of international linkage, production, consumption and trade of goods and services are aggregated into nine main agricultural sectors. The nine agricultural sectors include: wheat; rice; coarse grains; bovine and ovine meat; dairy products; other meat and fish; oilseed cakes and protein meals; other food; non-food agriculture. The rest of the economy is coarsely aggregated into one simplified non-agricultural sector. Agricultural commodities may be used in the model for human consumption, feed, as biofuel feedstock, for intermediate consumption, and stock accumulation. The non-agricultural commodity contributes also as investment, and as input for processing and transporting agricultural goods. All physical and financial accounts are balanced and mutually consistent: the production, consumption, and financial ones at the national level, and the trade and financial flows at the global level.

Linkage of country and country-group models occurs through trade, world market prices, and financial flows. The system is solved in annual increments, simultaneously for all countries in each time period. Within each one-year time period, demand changes with price and commodity buffer stocks can be adjusted for short-term supply response. Production in the following marketing year (due to time lags in the agricultural production cycle) is affected by changes in relative prices. This feature makes the world food model a recursively dynamic system.

The market clearing process results in equilibrium prices, i.e. a vector of international prices such that global imports and exports balance for all commodities. These market-clearing prices are then used to determine value added in production and income of households and governments.

Within each regional unit, the supply modules allocate land, labor and capital as a function of the relative profitability of the different crop and livestock sectors. In particular, actual cultivated acreage is computed from both agro-climatic land parameters (derived from AEZ) and profitability estimates. Once acreage, labor and capital are assigned to cropping and livestock activities, yields and livestock production is computed as a function of fertilizer applications, feed rates, and available technology.

The IIASA world food system model has been calibrated and validated over past time windows and successfully reproduces regional consumption, production, and trade of major agricultural commodities in 2000. Several applications of the model to agricultural policy and climate-change impact analysis have been published (e.g. Fischer et al., 1988; Fischer et al., 1994; Rosenzweig and Parry, 1994; Fischer et al., 2002b; Fischer et al., 2005; Tubiello and Fischer, 2006).

## ANNEX 2: AGGREGATION OF WORLD FOOD SYSTEM COMPONENTS TO WORLD REGIONS

| **Economic group** | **Region** | **WFS Component** |
|---|---|---|
| DEVELOPED | North America | Canada, United States |
| | Europe & Russia | Austria, EC-9, Eastern Europe, Former USSR, Turkey |
| | Pacific OECD | Australia, Japan, New Zealand |
| DEVELOPING | Africa, sub-Saharan | Kenya, Nigeria,<br>Africa Oil Exporters,<br>Africa medium income/food exporters,<br>Africa low income/food exporters,<br>Africa low income/f exporters |
| | Latin America | Argentina, Brazil, Mexico,<br>Latin America high income/food exporters,<br>Latin America high income/food importers,<br>Latin America medium income |
| | Middle East & North Africa | Egypt,<br>Africa medium income/food importers,<br>Near/Middle East oil exporters,<br>Near/Middle East medium-low income countries. |
| | Asia, East | China,<br>Far East Asia high-medium income/food importers |
| | Asia, South/Southeast | India, Pakistan, Indonesia, Thailand,<br>Asia low income countries<br>Far East Asia high-medium income/food exporters |
| REST of WORLD | Rest of World | Rest of the world |

### Aggregate Regional Country Group Models:

*African Oil Exporters*: Algeria, Angola, Congo, Gabon.
*Africa, Medium Income, Food Exporters*: Ghana, Cote d'Ivoire, Senegal, Cameroon, Mauritius, Zimbabwe.
*Africa, Medium Income, Food Importers*: Morocco, Tunisia, Liberia, Mauritania, Zambia.
*Africa, Low Income, Food Exporters*: Benin, Gambia, Togo, Ethiopia, Malawi, Mozambique, Uganda, Sudan.
*Africa, Low Income, Food Importers*: Guinea, Mali, Niger, Sierra Leone, Burkina Faso, Central African Republic, Chad, Democratic Republic of the Congo, Burundi, Madagascar, Rwanda, Somalia, United Republic of Tanzania.

*Latin America, High Income, Food Exporters*: Costa Rica, Panama, Cuba, Dominican Republic, Ecuador, Suriname, Uruguay.
*Latin America, High Income, Food Importers*: Jamaica, Trinidad and Tobago, Chile, Peru, Venezuela.
*Latin America, Medium Income*: El Salvador, Guatemala, Honduras, Nicaragua, Colombia, Guyana, Paraguay, Haiti, Bolivia.

*South East Asia, High-Medium Income, Food Exporters*: Malaysia, Philippines.
*South East Asia, High-Medium Income, Food Importers*: Republic of Korea, Democratic People's Republic Korea, Laos, Vietnam, Cambodia.
*Asia, Low Income*: Bangladesh, Myanmar, Nepal, Sri Lanka.

*Near/Middle East, Oil Exporters*: Libya, Iran, Iraq, Saudi Arabia, Cyprus, Lebanon, Syria.
*Near/Middle East, Medium-Low Income*: Jordan, Yemen, Afghanistan.

Note: The *Rest of the World* aggregate includes both more and less developed countries. Although the aggregate variables in ROW are dominated by more developed countries of the OECD, these are not included with the respective broad regional aggregates, DEVELOPED and DEVELOPING.

# INVESTMENT REQUIREMENTS UNDER NEW DEMANDS ON WORLD AGRICULTURE:

## FEEDING THE WORLD WITH BIOENERGY AND CLIMATE CHANGE

**Siwa Msangi, Simla Tokgoz, Miroslav Batka and Mark Rosegrant***

## SUMMARY:

In this paper, we explore the sectoral spending that is needed to sustain global agricultural food production at the level needed to feed the world to 2050. We examine the key sectors most closely associated with agricultural performance and human well-being improvement, and see how these sectoral needs change under the additional challenge of the future climate change. The results of our analysis reveal a significant level of additional spending needed for key regions like sub-Saharan Africa and South Asia, which hold most of the world's poor and undernourished, and which will be hard-hit by climate change. The role of irrigation becomes important for regions like Africa, which heavily depend on rainfed agricultural production. The need for roads is also crucial as a means for increasing the market access of producers and maintaining a vigorous level of performance within agriculture and other sectors. We discuss the role of the international agricultural research system in terms of providing global public goods, in the form of research innovations that benefit the global food system through both higher levels of availability, under increasing environmental and socio-economic stress, and through lower food prices.

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## 1. INTRODUCTION

The role and significance of key global drivers of agricultural supply and demand have been at the forefront of the policy debate that has emerged over the last two years, given the dynamics of food and energy prices that have been observed in global and national markets (Evans, 2008; FAO, 2008). The underlying factors to these rapid increases in food prices are varied – both in nature and in their relative strength in driving the market dynamics across various commodities. Among the large number of factors that have been attributed to the volatile state of food prices, are the rapid increase in first-generation, food-based production of biofuels (Oxfam International, 2008; Runge and Senauer, 2008), as well as the increase of cereal and meat and dairy demand from East and South Asia, and the possibility of increased speculative trading and purchasing activity in food markets. Several comprehensive discussions of this issue have appeared in recent literature, and try to assess the relative merit of each of these factors – while also including an overview of the global macro-economic picture, and the relative decline of the dollar, in relation to other currencies (Abbot et al., 2008). The steady decline in the global level of cereal stocks as a result of various factors including the private sector taking over the operation of cereals stocks from government (Trostle, 2008), has also been cited as a factor that has reduced the ability of national governments to stabilize consumer and producer prices (OECD, 2008). Most authors, however, do not isolate a single cause as being to blame for the current world food situation, but cite a complex interaction between several coincident factors.

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The challenges and increased stresses that face global food production and distribution systems, in the present economic climate, are particularly acute and pressing for sub-Saharan Africa, where roughly thirty-three percent of the population of sub-Saharan Africa lives with insufficient food supplies (FAO, 2005) and an even greater proportion, forty-three percent, lives below the international dollar poverty line (Dixon et al., 2001). The constraints that lie in the way of Africa benefiting from higher producer prices of agricultural commodities on the world market are myriad, and include the fact that most of Sub-Saharan Africa's agricultural production relies on rainfed cultivation, and receives lower input levels of improved seed technology and fertilizer applications relative to other regions.

In this paper, we look at the resources and investment needs for agriculture for sustaining the required growth in food production through the medium- and long-term periods, and the additional challenges that climate change and other environmental stresses are likely to present. We discuss the necessity for widely-available agricultural research benefits and innovations, and look at the role of the international agricultural research system from the perspective of providing global public goods. Next, we examine the baseline case of growth to 2050, in order to understand the relative size and distribution of investment needed in both the key agricultural and non-agricultural sectors most closely associated with food security and human well-being, and then examine the additional needs that climate change will likely require. Based on this analysis, we conclude with some final recommendations for both policy action and interventions, as well as for further research and analysis.

## 2. INVESTMENTS TOWARDS AGRICULTURE

### 2.1 Agricultural R&D relative to other drivers of change

There are a number of underlining factors that drive the long-term trends in global food supply and demand that have also contributed towards a tightening of global markets in the past decade. These trends are driven by both environmental and socio-economic changes, as well as by agricultural and energy policy, including those which govern investments of public and private entities towards agricultural research and development. Figure 1 illustrates the interactions between the various key 'drivers' of change in global food systems, and their linkage to other components of the food economy and to important outcomes of human well-being – such as nutrition (Figure 1).

While this schematic is not completely exhaustive of all the major factors of importance, it incorporates the main elements of global environmental and economic change in food production and consumption systems, that we hope to address in this paper. While Figure 1 does show how the various drivers of change interact with each other, and where the critical feedback loops might be – it does not provide us with the type of distinguishing characteristics that can explain short-lived and long-lived effects on food systems. Figure 2, however, does more to make this distinction, and shows where some key drivers of change lie in relationship to each other, with respect to their dynamic characteristics – which is a combination of the speed with which they act, as well as the degree to which they explain short-term or long-term phenomena (Figure 2).

Aside from the drivers of socio-economic change, in the form of increasing growth in population numbers and total income, which constitute the major factors that govern the change in demand for food and energy products over time, there are a number of key supply-side drivers which must be taken into account. A number of key environmental factors might restrain the supply side of food systems from responding readily and consistently to changes in demand – as a result of either resource scarcity or degraded land and water quality. Reduced research investments in crop and energy technology could also lead to a longer-term slowdown in the expansion of supply – which eventually leads to higher prices, as demand continues to grow. This is the particular aspect of the global food problem that we address in this paper, to better understand how the current and past trends in agricultural research investments can result in a less resilient agricultural system and a more food-insecure future, given the challenges that the climate change and the bioenergy present to the global food economy.

A number of future assessments of global food production and consumption show projections of future agricultural land requirement that assume that 70 percent of food needs will be met through yield enhancements

(FAO, 2006). Yet, agricultural research has stagnated or declined over the years for many regions particularly after the 1990's (Table 1). For developing countries, public agricultural research investments increased by 37.4 percent between 1991 and 1981, where this growth rate declined to 21.8 percent between 2000 and 1991. For developed countries, this decline is even sharper; the growth rate declined from 28.7 percent to 5.9 percent for the same time frame. For sub-Saharan Africa, which is particularly vulnerable to food security problems, public research investments actually declined. Given the vast number of studies that show the existence of significant R&D spillovers, a decline or stagnation of research in any of these regions may have adverse impacts agricultural productivity in other regions as well. Table 1 also presents the agricultural research expenditures as a percentage of agricultural GDP. It can be seen that this share has declined for sub-Saharan Africa over the years, whereas it increased only slightly in the other regions (Table 1).

As the United States of America and other developed regions have shifted their research focus to reflect consumer preferences for processed, organic, and humane products, the diffusion of more relevant yield enhancing technology in developing countries has slowed (Pardey *et al.,* 2006). Only one-third of the global public agricultural research in the 1990s was in developing countries, with over 50 percent being concentrated in Brazil, China, India, and South Africa (Pardey *et al.,* 2006). Therefore, better technology diffusion and more public funds dedicated to developing country research programs are critical to meet the growing food needs.

## 2.2 Agricultural productivity and the 'public goods' problem

Global agricultural production has a multifaceted and widely-varied landscape that encompasses a wide range of farming systems and agro-ecologies. The distribution of crop species has been governed by a gradual diffusion of technology and knowledge that has evolved over decades and centuries of innovation, knowledge-sharing, dissemination, commercial interaction, and natural dispersion by environmentally-driven forces of change. As a result of this, there are a number of characteristics of the wider agricultural technology portfolio that are public as well as private in nature. On-farm technologies and capital can be considered as fully privatized and within the control of the individual (or household) that has acquired it through purchase or gradual acquisition and accumulation over time. Aside from individual know-how, intelligence, ingenuity and gifted-ability, a great deal of agricultural knowledge can also be accumulated or purchased from the market, in the form of hired expertise or education. Agricultural extension constitutes a publicly-provided good which has limits to scope and coverage, at the country-level, and might not be sufficient in quantity and quality to benefit all those who need it. The global pool of agricultural technology and knowledge that consists of various plant genetic resources, improved seed varieties that have varied abilities within different agro-ecologies and environmental regimes, can be thought of as the knowledge that is embodied in the international agricultural research centers (IARCs) and global bodies such as the Food and Agricultural Organization (FAO) of the United Nations and other regionally- and internationally-sponsored (and funded) bodies.

While many would agree on the utility and benefits provided by the system of international research bodies and affiliated organizations, in terms of strengthening the performance and resilience of agriculture both at a regional and global scale, the question of how to finance such a system of centers remains open to debate – as it is not in the interests of any one organization or government to donate resources towards an entity whose benefits will diffuse well beyond the scope of its constituents or borders. Aside from the questions of accountability and governance, the long-term goals and objectives of such agricultural research organizations extend beyond the usual time horizon that national politicians would care to consider, when they contemplate the opinions of the constituents who elect them, and the short-term actions that are needed to influence them. Therefore, there remains a mismatch in objectives and incentives when we consider the motives that underlie the decision to make investments or contributions towards agricultural research and crop productivity improvement.

### *The voluntary contributions problem*

We use a simple example to illustrate the problem of individual agencies (or countries) making voluntary contributions towards agricultural research, when the benefits of those contributions cannot be fully appropriated or captured by them, and extend beyond the scope of their constituents' interests. This 'voluntary contributions' problem[1] contains the key elements of a non-cooperative strategic equilibrium, and is a well-understood case from the public economics literature, which demonstrates the properties of a sub-optimal, Nash equilibrium outcome. In other words, we obtain a final outcome that results in lower overall welfare than that which would happen if a more altruistic and all-encompassing outlook were used to decide on the optimal level of investment to place in public research to enhance global agricultural productivity.

To illustrate this problem, we take a simple case in which we hypothesize a national entity (or a representative agent who acts on behalf of the national good) and who derives 'utility' (benefit) from the consumption of both food and non-food goods ($c_f, c_{nf}$) within the country. The consumption of these goods, however, must be balanced with the contribution ($x$) that must be made towards a global public good (agricultural productivity research) that enables the production of the food good to be sustained and made available (through trade or food aid, *f.ex.*) at the global level. As the national entity must make this contribution (along with *N-1* other nations), and do so at the expense of the national budget, then there is a trade-off that arises in the mind of the national decision-maker between the national utility of consuming both the food and non-food goods, and the contribution that must be made (at the expense of non-food consumption) towards the global public good, which is generated through voluntary contributions.

Following the logic of Laffont (1988), we represent the national entity's utility as being separable between the consumption of the non-food good which is financed from the national 'treasure' and of the food good (which is enabled by the global public good), such that

$$u^i\left(c^i_{nf} - x^i, c^i_f\right)$$
$$\text{where}$$
$$c^i_{nf} + x^i \leq Y^i \quad \text{and} \quad c^i_f = g_f\left(x^i + \sum_{-i} x^{-i}\right)$$

Where the creation of the global public good depends on the contribution of each national agency *i* and all other nations (*-i*), and where the national income is $Y^i$. In the case where this utility is being maximized at the country-level, we can assume that choices will be made such that the national budget is spent (and the constraint is binding), so that we can represent non-food consumption as ($Y^i - x^i$), and we can substitute the equation that relates food consumption to the public good, such that expression for national utility becomes

$$u^i\left(Y^i - x^i, c^i_{nf}\right) = u^i\left(Y^i - x^i, g_f\left(x^i + \sum_{-i} x^{-i}\right)\right) = u^i_1\left(Y^i - x^i\right) + u^i_2\left(g_f\left(x^i + \sum_{-i} x^{-i}\right)\right)$$

assuming that a separability exists between the food and the non-food consumption, in the national utility function. Using simple logarithmic functions, we can translate our conceptual framework into the following maximization problem

$$\max_{x^i} \quad \alpha \log\left(Y^i - x^i\right) + \beta \log\left(g_f\left(x^i + \sum_{-i} x^{-i}\right)\right)$$

[1] For further details on these kind of public economics problems, see Laffont (1988).

where the individual level of contribution towards the global public good ($x^i$), is the only decision variable for the national agency. We obtain the following necessary condition, for the maximization of the national agent's utility[2]

$$\frac{-\alpha}{Y^i - x^i} + \frac{\beta}{g_f\left(x^i + \sum_{-i} x^{-i}\right)} g_f{}'\left(x^i + \sum_{-i} x^{-i}\right) = 0 \quad \rightarrow \quad \frac{\alpha}{Y^i - x^i} = \beta \cdot \frac{g_f{}'\left(x^i + \sum_{-i} x^{-i}\right)}{g_f\left(x^i + \sum_{-i} x^{-i}\right)}$$

If we impose the symmetry condition, of a Nash equilibrium, in which each agent conjectures that the actions of all the other *N-1* players will be identical to their own, then we can re-write the maximization condition after substituting $\tilde{x}^i = \tilde{x}^{-i} = \overline{x}$, to obtain

$$\frac{\alpha}{Y - \overline{x}} = \beta \cdot \frac{g_f'\left(N \cdot \overline{x}\right)}{g_f\left(N \cdot \overline{x}\right)}$$

if we take the function $g_f$ $g_f(\square)$ to be a simple linear function ($g_f(x) = k \cdot x$), then we would obtain the following relationship

$$\frac{\alpha}{Y - \overline{x}} = \beta \cdot \frac{g_f'\left(N \cdot \overline{x}\right)}{g_f\left(N \cdot \overline{x}\right)} = \beta \cdot \frac{k}{k \cdot N \cdot \overline{x}} = \frac{\beta \cdot}{N \cdot \overline{x}} \quad \rightarrow \quad Y - \overline{x} = \frac{\alpha N}{\beta} \cdot \overline{x}$$

which results in a Nash equilibrium, in which the optimal decision of each national agent is given by

$$\overline{x} = \frac{Y}{1 + \frac{\alpha N}{\beta}}$$

From this result, we can see that as the number of agents increases – the level of voluntary contributions from each individual decreases, monotonically (i.e. $\overline{x} \rightarrow 0 \text{ as } N \rightarrow \infty$).

This result can be contrasted with that of the 'global social planner' who considers the welfare of all *N* nations, and solves the problem, below

$$\max_x \quad N \cdot \left[ \alpha \log\left(Y - x\right) + \beta \log\left( g_f\left( \sum_{i=1}^{N} x^i \right)\right)\right]$$

which results in the solution $\hat{x} = \frac{Y}{1 + \frac{\alpha}{\beta}} > \overline{x} = \frac{Y}{1 + \frac{\alpha N}{\beta}}$, and a higher level of contributions to the global public good, than under the Nash equilibrium outcome.

In reality, the problem of providing for a global good through a contributory scheme can also have elements of foresight (versus myopia) involved, whereby the long-term benefits might be overlooked by an agency that is much more short-sighted in terms of their policy horizon – which are usually bounded by the span of periodic election cycles for national politicians. We will not address the issue of myopia analytically, here, but appeal to

[2] which is obtained by taking the derivative with respect to *x*

the reader's intuitive expectation that a far-seeing global agency would do better at providing for a public good than a short-sighted national agency would.

## 3. GLOBAL OUTLOOKS FOR AGRICULTURE AND INVESTMENT

In this section, we present some empirical examples to illustrate the importance of investments in agriculture, and the implications that sub-optimal policies can have for future food production and human well-being, if attention is not paid by policy makers. Before delving into the particulars of the investment scenarios that are illustrated, we take some time to explain the methodological approach used in calculating the future investment needs in agriculture.

### 3.1 Methodology used for quantifying necessary agricultural spending

The types of investment and sectoral spending that are tracked within the IFPRI modeling framework are spread over 3 key areas:

(1) Direct investment in agricultural research and development spending
(2) Investment in key sectors that are strongly linked to agricultural productivity growth – roads and irrigation
(3) Expansion of non-agricultural services and sectors that have been shown to have highly positive impacts on human well-being improvement – especially the reduction of malnutrition and hunger. Chief among these areas of spending are those of education (especially female secondary schooling), the provision of clean drinking water (and accompanying improvements in sanitation) and expansion of healthcare services that result in significant improvements in human life expectancy.

These areas of spending represent the sectors that have, empirically, the most significant impact upon the human well-being measure of malnutrition in the highly vulnerable demographic of pre-school children which are tracked in the simulations of the IFPRI agricultural policy model (IMPACT) (Rosegrant *et al.*, 2001). The linkages created between these sectors and the model outputs are shown in the schematic, in Figure 3, and illustrate the areas in which various drivers of socio-economic growth, policy and environment can interact with elements of the food system to lead to different outcomes of nutrition and human well-being (Figure 3).

In trying to account for how the influence of agricultural spending leads to improvements in agricultural performance and, subsequently, to nutrition and well-being, we face a number of key challenges. The first of these challenges is to account for the lagged effects that expenditures on agricultural research have on productivity and performance of agricultural production systems. This is a topic that has been researched within a variety of settings – particularly that of the United States of America, where the data on agricultural research spending and regional-level agricultural production and yields are available over a long period (enabling detailed econometrics to be carried out). Such work has been carried out by key authors such as Alston *et al.* (1998, 2002) and Marra *et al.* (2002). The volume of work that has been carried out to document the impact of agricultural research spending in the developing work is far smaller, due to the data problems that are often encountered when attempting to obtain a long enough time series over which to carry out empirical estimation and measurement. A few key examples that we have drawn upon are those of Alene and Coulibaly (2009), who looked in detail at the Africa region. Another key data gap that we face in carrying out our own quantification is the level of agricultural research spending that has taken place in the Central Asian countries. The comprehensive database of Agricultural Science and Technology Indicators (ASTI) that is maintained by IFPRI, provides us with invaluable information, that has enabled us to plug many of the data gaps that would otherwise be insurmountable (ASTI 2009).

In terms of a final methodological note, we should point out that our approach to quantifying the investment needs in agriculture and other related sectors does not attempt to optimize across the various options, in order to come up with a least-cost solution to increasing agricultural sector performance. In many ways, this would be an appealing approach to take, and would be in the spirit of a normative analysis that attempts to guide investment decisions in the best possible manner, so as to maximize social welfare and gains. However, the definition of the objective function would be complicated – as it would most likely need to satisfy a number of goals and criteria, and not just a single objective. The weighting among these various goals that would result in the single scalar valued objective function value would also have to be subject to scrutiny and sensitivity analysis. While this remains an appealing direction of analysis, we defer it for now to further research, and adopt an approach which 'searches' in a less efficient manner over the space of interventions, for that which results in a "no-impact" solution with regard to a pre-defined outcome. In other words, we show how changes in the levels of spending in these sectors can offset the human costs of decreased agricultural performance and productivity, as measured through increases in the levels of child malnutrition, so that we can quantify the size of the interventions that might be necessary to offset shocks to food economies, such as those brought on by environmental shocks or policy-changes.

## 3.2 Baseline projections of spending needed for agriculture

In this section, we present some projections of spending on agriculture that are anticipated under a baseline set of assumptions, regarding the growth of crop yields and productivity in agriculture. We will contrast the baseline case with one in which there is an effort to offset the effects of climate change – as envisioned under one of the more severe climate scenarios – in order to illustrate the levels of spending and improvement that are needed to address the challenges that global environmental change will pose to the global food system.

By looking at the baseline case to 2050, projected with IFPRI's IMPACT model, we see that the implied spending across both the agricultural and non-agricultural sectors implies sizable outlays of resources, in order to meet the future needs for food, feed and fuel (Table 2).

From this table, we see that a sizable outlay of expenditure is still needed in South Asia to maintain its irrigation system, in order to continue the successes and the momentum of the green revolution. This is reflected in the strong increases in irrigated area that are projected to continue in South Asia, compared to what is seen in other regions (Figure 4).

Even though there are increases in irrigated area in sub-Saharan Africa, they are modest in size, compared to other regions – which reflects that historical difficulty in realizing successful irrigation investments there, and the notoriously high costs of those which are implemented (IWMI, 2005). For the rest of Asia and the Pacific, clean water investments remain the largest category for which future spending needs lie. There is also a higher share of regional spending that is allocated to rural road access, compared to South Asia. The region that has the highest share of its expenditure allocated to rural road access is sub-Saharan Africa followed closely by Latin America and the Caribbean (Table 3).

The largest amount of spending that is envisioned for agricultural research is in Latin America and the Caribbean as seen in Table 2,which is necessary to change the pattern of historical production growth which has mostly come from land expansion, into a future pattern of growth that relies more on yield increases. The future changes in regional environmental conditions across Latin America, in future, will also require it to adapt its agricultural sector, accordingly.

For the sub-Saharan Africa region, a more even spread of the investment outlays is envisioned across all components of the agricultural sector. The largest category of spending for sub-Saharan Africa, across all sectors, is that of improving access to clean water. Given that access to clean drinking water is such an important part of household health and welfare, and the fact that it has been slow to spread to those parts of rural sub-Saharan Africa that need it most, it remains a 'big ticket' item on Africa's spending bill. Irrigation investments is the second largest component to counteract the historically very low rate of irrigation expansion and adoption across the continent, South Asia also has a large outlay of expenditure for improving access to clean water, given the large number of the poor and the malnourished in that region. Figure 5, below, shows the change in the levels of access to clean water across various regions, which are used as exogenous assumptions in the IMPACT simulations.

Spending on female secondary education is also a large portion of the non-agricultural spending portfolio for both Asia and sub-Saharan Africa, given that it has also accounted for a large share of the reduction in child malnutrition seen in the past years, and because the rapidly growing populations of these regions are projected to have sizable increases in the population of school-age girls in the coming years (Table 2). Figure 6 shows the rates of female secondary school enrollment that are embedded into our baseline simulations, and which imply increasing numbers of girls that are educated over time.

Therefore in order to maintain, and continue to improve the enrollment rates of females in secondary school, the pace of future expenditure has to increase into the future in order to accommodate these new pupils.

### 3.3 Addressing the challenge of climate change in agriculture

Now we examine the case where we introduce a climate change scenario, into our modeling framework, and simulate the projected shocks to agricultural production and the future patterns of food consumption, availability, and malnutrition that result from that. We then carry out a policy experiment, in which we introduce yield improvements to the affected crops and regions, and determine the additional levels of agricultural sector spending, above the baseline case, that are necessary to offset the shocks introduced by climate change. The results provide us with insight into which countries are most affected by the climate change shocks, and where the additional spending on agriculture is needed more. The results of this scenario analysis will provide policy makers and agricultural researchers and scientists with a sense of prioritization of their efforts in coming years.

For this experiment, we take a more ‘extreme’ climate change scenario, generated by the Hadley Center’s climate change model. The IPCC’s “A2a” scenario provides us with such a case, where we have rather sharp decreases in precipitation for South Asia, as well as key parts of sub-Saharan Africa and Latin America. Table 4 shows us the additional expenditure within the agricultural sector that we see as necessary to bringing the world food system back to the “no climate change” case.

From this table, we see that sub-Saharan Africa requires the largest level of spending in agriculture, in order to offset the impacts of climate change, as measured within this modeling framework. Within that total spending level for Africa, the amounts for irrigation and agricultural R&D are close in magnitude. The level of investment needed in rural roads is more than quadruple of the amount of investments needed in all the other sectors combined. Given the poor state of road networks in Africa, and the large share of the population that is projected to remain rural in the future (implying higher road costs necessary to reach them), the levels of spending in this category are relatively large, compared to other regions, and constitute a significant increase over the baseline spending needs for roads. The next largest level of outlay in roads is Latin America, given its relatively low population density, compared to Asia, which also raises the costs of reaching people by road.

The additional spending on agricultural research is highest in sub-Saharan Africa among all regions, followed by Latin America and the Caribbean region and the Middle East and the North Africa region. These additional spending requirements show the need to maintain the increases in yield growth (over area expansion) that are required in order to produce the high volume of cereals needed for food and feed, as environmental and socio-economic changes occur to 2050.

## 4. IMPLICATIONS FOR FOOD SECURITY AND POLICY

In light of these impacts, and given the nature of the policy problem that we have previously described, within the context of the various global and regional drivers of change, we might consider several possible entry points for policy intervention, which might address the global food situation and the challenges that will be faced to 2050. As is shown in Figure 1, there are a number of interventions which we could consider that will impact the supply side response to continuing demand growth. The first is to boost the output of cereals by raising yield levels over time through policies that accelerate the improvement of crop technologies. This can be done directly through improved seed technologies, which might enhance the productivity and hardiness of plant varieties, or through the expansion of area under irrigated production, which has a higher yield than the rainfed alternatives, typically. Improved seed technologies can even reduce the loss in productivity that occurs when irrigated crops become water-logged or subject to increased salinity and submergence – thus allowing the expansion of irrigated area to be even more effective in raising the overall production levels.

This suggests that a combination of policy interventions are necessary when dealing with the world food situation – in the same way that a complex combination of factors were originally responsible for its evolution towards the present state. The maintenance or acceleration of yield growth over time is another part of the policy combination that should also be pursued, as it will have a profound effect upon the trajectory that future food system dynamics will follow. There is also a long lag-period between the time that such investments are made, and the time higher growth potential is realized. Part of this call is now being taken up by the global development donor community, and will be followed up by increased commitments towards R&D spending from both the public and the private sources. It must, however, be accompanied by concurrent improvements in extension services and improvements in marketing and distribution infrastructure, which can only come from national governments and from concrete allocations in public spending, in order to be realized at the farmer/field-level. Regional development agendas, such as the Comprehensive African Agricultural Development Program (CAADP), are trying to lead regional policy bodies and national governments through the necessary steps of making these commitments towards agriculture-focused public spending increases – and require the analytical support of researchers and policy analysts to better refine their targets and define the appropriate domains for intervention.

Furthermore, due to the existence of significant R&D spillovers between countries and regions, investments in agricultural research in one country will also benefit other countries. Thus, for every dollar spent on R&D activities in a country, the resulting gains will be shared by multiple countries and regions. This further illustrates the importance of continuing R&D activities and generating knowledge that will help farmers increase their production and meet growing domestic and international demand.

In the case of climate change, a country experiencing sharp decreases in crop productivity due to more variable or adverse climatic conditions, can decide to decrease the area under cultivation of that crop within the country, and to meet its domestic demand through imports. On the other hand, the same country might decide to switch towards a more resilient crop variety, that is more tolerant of extremes in either temperature or rainfall conditions. However, this requires mechanisms that go beyond just trade movements, and needs a robust and productive system of agricultural research to make these improved varieties available. The improved varieties that come through the system of international agricultural research centers could provide these as global public goods, and supplement the efforts of those regions which still lack the capacity to produce them locally. This suggests a vital role for climate focused agricultural research for the future decades.

## 5. LIMITATIONS AND SCOPE FOR FURTHER WORK

In this paper, we have tried to quantify the additional requirements needed to maintain the necessary trajectory of growth and human well-being in face of the additional stresses posed to the food system through crop-based bioenergy growth and climate change. The particular sectors that we addressed our analysis to, however, are not exhaustive of the entire range of spending that will likely be needed to upgrade and reinforce the facets of the food system that will be most vulnerable to the pressures of these global drivers. In this analysis, we have not taken into account the expected replacement costs of on-farm capital, and how these might be accelerated with the affects of climate change – as little evidence exists to indicate what these costs would be. There are not additional food storage, distribution and processing capacity investments that are included in this analysis, nor are there any investments in improved information or early warning systems that could provide additional knowledge and decisions support to farm operators and managers to better adapt and adjust to emerging pressures and further improve the efficiency of the sector. The numbers that are given in this paper represent the additional level of spending that are critical to strengthening the particular linkages to human well-being that are described in figure 3. There is further work that we will do to refine the methodology of accounting for information resource needs, and other types of infrastructure that might not have been addressed here. There are also some aspects of adaptation that we have not been able to fully address, within the context of climate change. The ability of certain regions to improve efficiency, substitute labor-intensive for capital-intensive methods and upgrade material and equipment to increase yield and energy intensity has not been modeled explicitly, and will also be addressed in future work once better information is available. We, nonetheless, take our analysis as being strongly indicative of the key sectors that will warrant further attention and support in the coming decades.

## 6. CONCLUSIONS

In this paper, we illustrate the investment needs that are required to enable agricultural production and the wider food system to meet the challenges of feeding the world to 2050, under increased environmental and socio-economic stresses. Development and long-term economic growth will inevitably lead to more capital- and energy-intensive patterns of production over time. Within this context, it remains the role of technological efficiency improvements – in both industry and agriculture – to relieve the pressures that this growth will place on the natural resource base and on the landscape. This underscores the need for continued investment in yield-enhancing crop technologies that can lessen the reliance on crop area expansion to increase food production, that can improve the resilience of agriculture to climatic change and variability, as well as in technologies that can allow biofuel production to switch away from food-based feedstocks, towards those which can use non-staple and even non-edible plants or plant material. Having higher commodity prices might raise the returns that make investments in these areas more attractive, and, in the case of biofuels, for example, there might be the need for some support in first-generation biofuel sectors, in order to allow the second-generation to emerge more quickly. However, policymakers need to strike a careful balance between providing necessary incentives while also offering the protection that is needed for those who are most vulnerable.

This requires a more concentrated effort on the part of researchers and policy analysts to help identify where such opportunities might exist, and where the returns to investment might be the highest. Meeting the world’s growing needs for food, feed, and fuel will inevitably put greater pressure on production systems, and on the natural resources and ecosystems that support them. Therefore, balancing the needs of agricultural development and economic growth, with the goal of achieving long-term environmental sustainability and a diverse set of important goals for human well-being improvement, will require a concerted effort to coordinate development policy objectives, mobilize needed resources and deploy the necessary technologies and interventions where they are most effective and needed.

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**APPENDIX: FIGURES AND TABLES**

**Figure 1: The interrelationships between key drivers of change in food systems and their connection to human well-being**

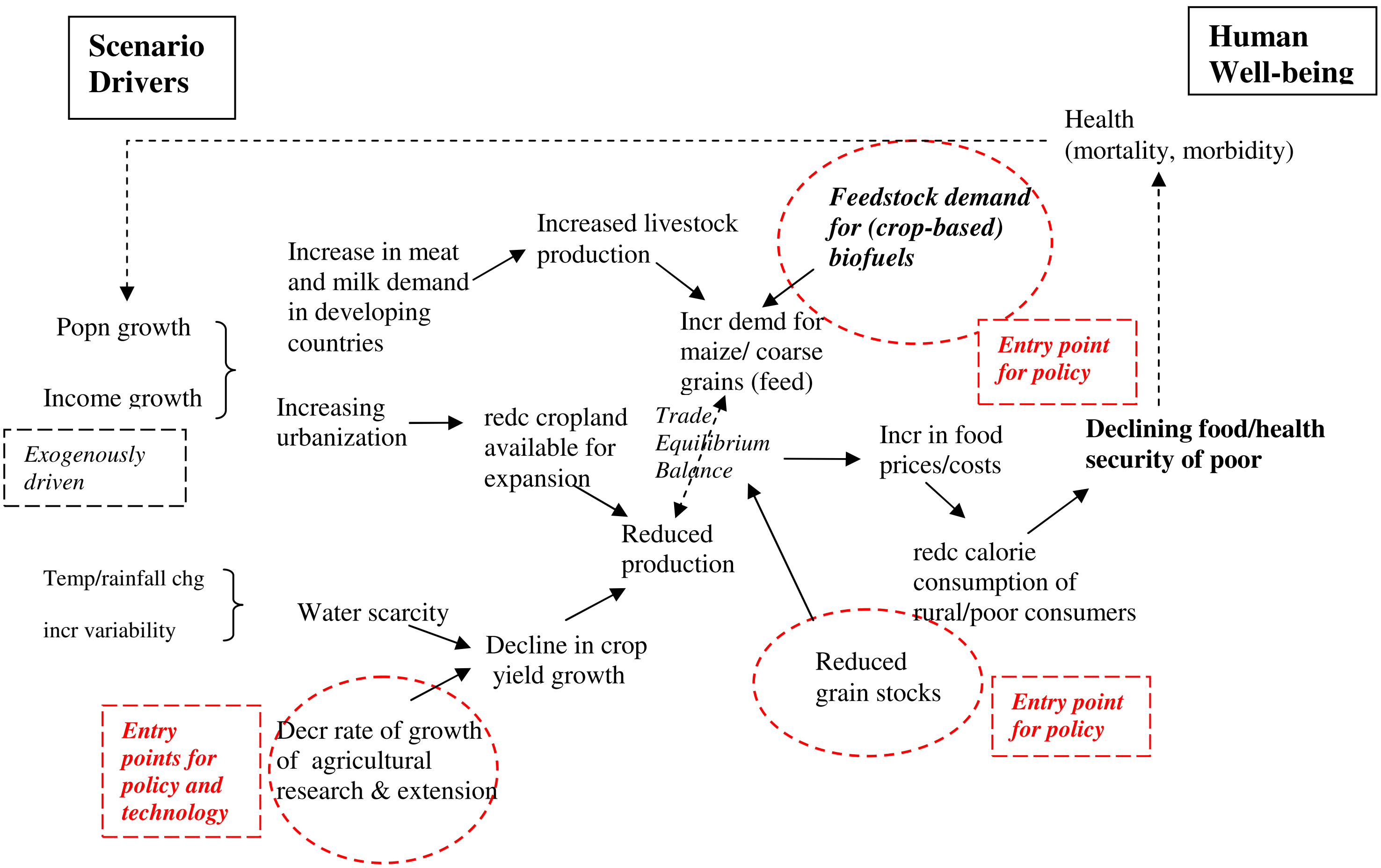


**Figure 2: Characteristics of various drivers of change in food systems**

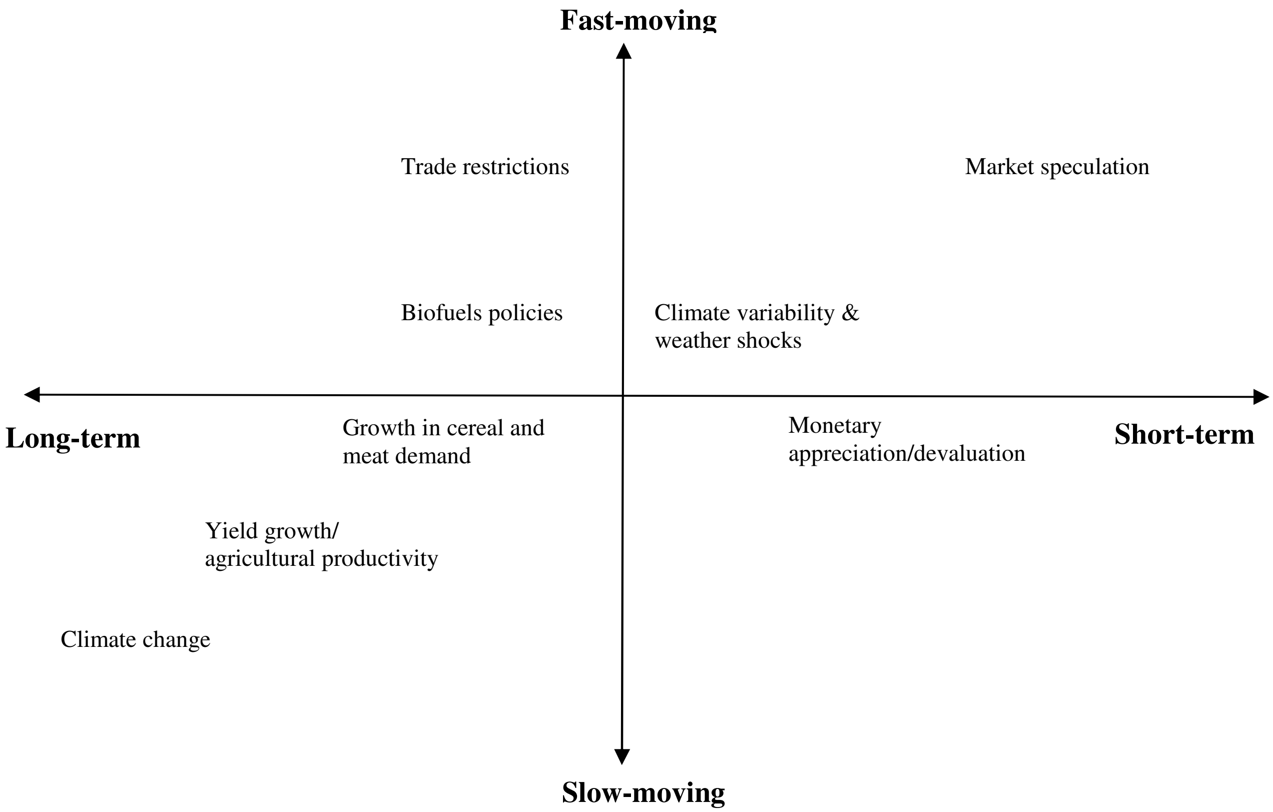


**Figure 3: Key entry points for policy and investment used in modeling**

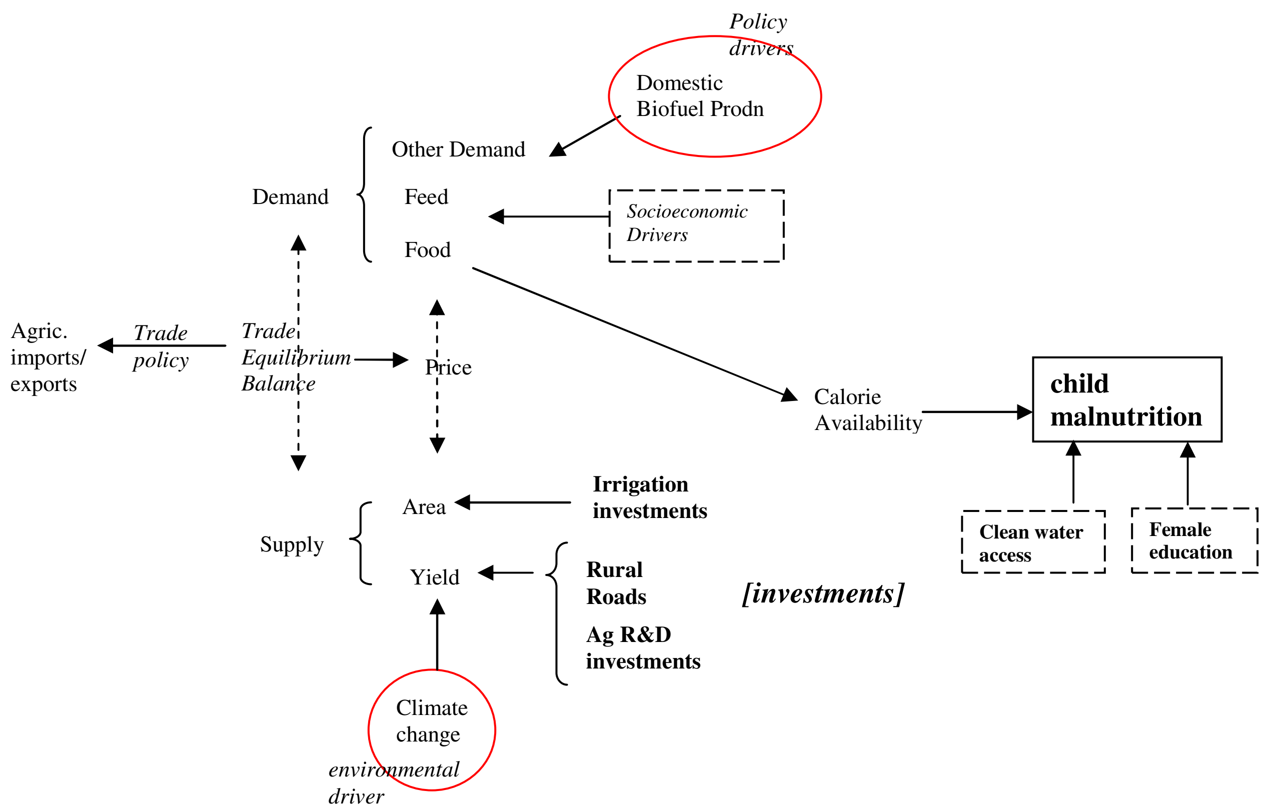
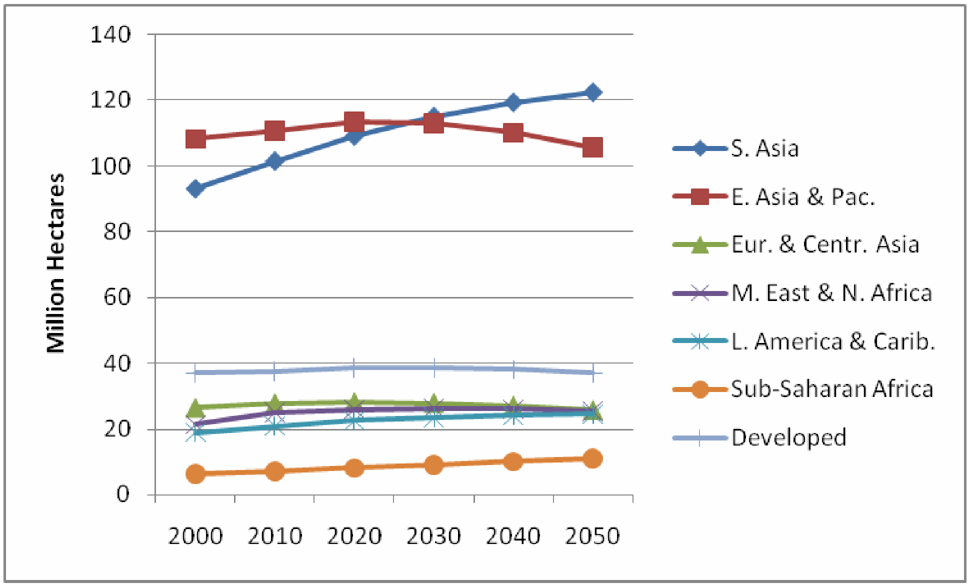
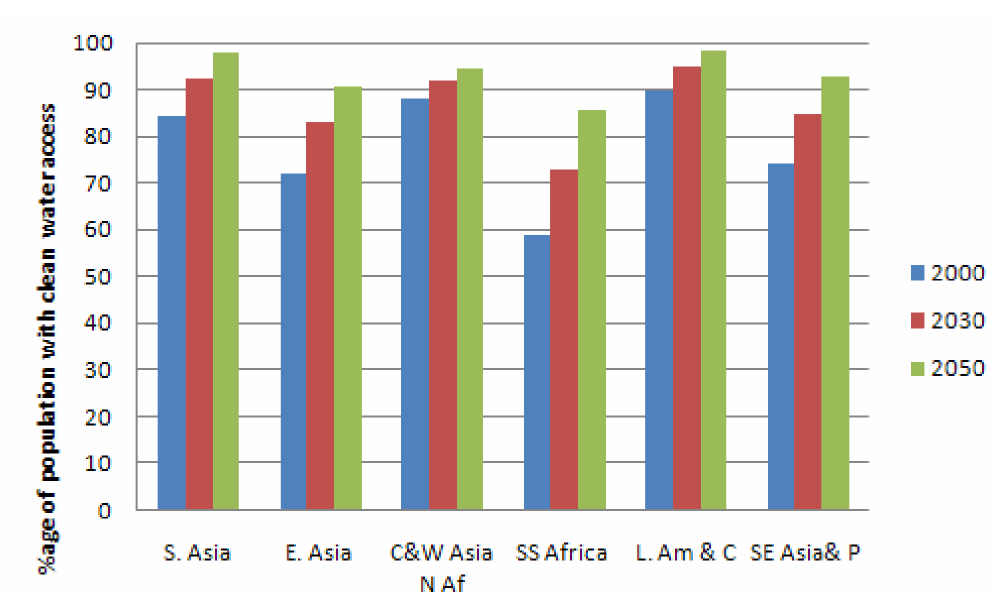


**Figure 4: Simulated increases in net irrigated area over time**



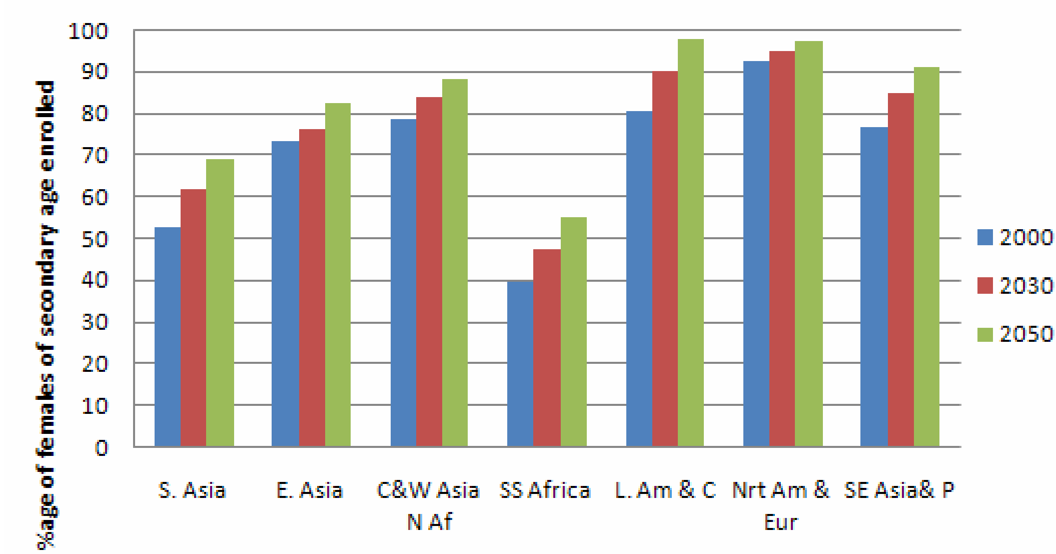

Source: IFPRI IMPACT projections.
Note: S Asia = South Asia, M. East & N. Africa = Middle East & North Africa, L. America & Carib. = Latin America & the Caribbean, E. Asia & Pac. = East Asia & Pacific, Eur. & Centr. Asia = Europe and Central Asia.

**Figure 5: Share of population with access to clean water over time**




Source: IFPRI IMPACT projections
Note: SS Africa = Sub-Saharan Africa, S Asia = South Asia, L. Am & C = Latin America & the Caribbean, E. Asia = East Asia, SE Asia & P = Southeast Asia and the Pacific, C&W Asia N AF= Central & Western Asia and North Africa.

**Figure 6: Female secondary schooling rates over time**




Source: IFPRI IMPACT projections.
Note: SS Africa = Sub-Saharan Africa, S Asia = South Asia, L. Am & C = Latin America & the Caribbean, E. Asia = East Asia, SE Asia & P = Southeast Asia and the Pacific, C&W Asia N AF= Central & Western Asia and North Africa.

**Table 1: Public expenditures in agriculture-related research, 1981-2000**

| Region/Country | Expenditures as a % of Agricultural GDP | | | Public agricultural R&D spending (2005 PPP dollars, millions) | | |
|---|---|---|---|---|---|---|
| | 1981 | 1991 | 2000 | 1981 | 1991 | 2000 |
| Low and Middle Income Countries | 0.56 | 0.56 | 0.55 | 6,049 | 8,310 | 10,119 |
| Sub-Saharan Africa | 0.86 | 0.76 | 0.65 | 1,084 | 1,253 | 1,239 |
| Asia and Pacific | 0.33 | 0.37 | 0.39 | 1,971 | 3,287 | 4,758 |
| Latin America and Caribbean | 0.91 | 1.08 | 1.19 | 2,274 | 2,697 | 2,710 |
| Middle East and North Africa | 0.60 | 0.60 | 0.74 | 720 | 1,074 | 1,412 |
| High Income Countries | 1.51 | 2.08 | 2.35 | 9,774 | 12,577 | 13,313 |
| Total | 0.91 | 1.00 | 0.98 | 15,823 | 20,887 | 23,432 |

Source: ASTI (2009)

**Table 2: Baseline results for agricultural and non-agricultural sector investments for the years 2000-2050 (billions of 2000 US dollars)**

| | Agricultural Research | Clean Water | Education | Irrigation Expansion | Irrigation Efficiency | Rural Roads |
|---|---|---|---|---|---|---|
| South Asia | 25 | 63 | 24 | 36 | 30 | 10 |
| East Asia and Pacific | 35 | 45 | 20 | 6 | 19 | 43 |
| Europe and Central Asia | 30 | 5 | 1 | 1 | 4 | 2 |
| Latin America and Caribbean | 58 | 27 | 6 | 8 | 11 | 65 |
| Middle East and North Africa | 21 | 13 | 4 | 5 | 1 | 2 |
| Sub-Saharan Africa | 21 | 66 | 16 | 44 | 5 | 112 |
| All Developing | 190 | 219 | 72 | 99 | 70 | 235 |

Source: IMPACT model projections

**Table 3: Breakdown of agricultural sector investment needs under baseline case for the years 2000-2050 (billions of 2000 US dollars)**

| | Total Agricultural Spending | Share of Total Agricultural Spending | | | |
|---|---|---|---|---|---|
| | | Agricultural Research | Irrigation Expansion | Irrigation Efficiency | Rural Roads |
| South Asia | 101 | 24% | 36% | 30% | 10% |
| East Asia and Pacific | 102 | 34% | 6% | 19% | 42% |
| Europe and Central Asia | 38 | 80% | 3% | 11% | 5% |
| Latin America and Caribbean | 142 | 41% | 6% | 8% | 46% |
| Middle East and North Africa | 29 | 74% | 16% | 2% | 9% |
| Sub-Saharan Africa | 182 | 12% | 24% | 2% | 62% |
| Developing | 593 | 32% | 17% | 12% | 40% |

Source: IMPACT model projections

**Table 4: Additional spending needs for agricultural sector to offset climate change impacts**

**Breakdown of Total Spending in Agriculture (billions US $)**

| | Agricultural Total | Agricultural Research | Irrigation Expansion | Irrigation Efficiency | Rural Roads |
|---|---|---|---|---|---|
| South Asia | 78 | 10 | 14 | 35 | 19 |
| East Asia and Pacific | 52 | 10 | 2 | 29 | 11 |
| Europe and Central Asia | 13 | 6 | - | 7 | 0 |
| Latin America and Caribbean | 62 | 12 | 3 | 13 | 35 |
| Middle East and North Africa | 16 | 12 | - | 3 | 4 |
| Sub-Saharan Africa | 171 | 15 | 12 | 7 | 138 |
| Developing | 392 | 65 | 30 | 93 | 208 |

**Increase in spending over baseline levels**

| | Agricultural Total | Agricultural Research | Irrigation Expansion | Irrigation Efficiency | Rural Roads |
|---|---|---|---|---|---|
| South Asia | 78% | 43% | 38% | 115% | 190% |
| East Asia and Pacific | 50% | 29% | 30% | 151% | 26% |
| Europe and Central Asia | 33% | 21% | 0% | 157% | 19% |
| Latin America and Caribbean | 44% | 21% | 35% | 116% | 53% |
| Middle East and North Africa | 56% | 55% | 0% | 638% | 178% |
| Sub-Saharan Africa | 94% | 69% | 27% | 146% | 123% |
| Developing | 66% | 34% | 30% | 133% | 89% |

Source: IMPACT model projections

# CAPITAL REQUIREMENTS FOR AGRICULTURE IN DEVELOPING COUNTRIES TO 2050[1]

**Josef Schmidhuber, Jelle Bruinsma and Gerold Boedeker[2]**

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[1] Paper presented at the FAO Expert Meeting on "How to Feed the World in 2050", 24-26 June 2009, Rome.
[2] Global Perspective Studies Unit, FAO.
The views expressed in this information product are those of the author(s) and do not necessarily reflect the views of FAO.

## SUMMARY AND CONCLUSIONS

Cumulative gross investment requirements for developing countries' agriculture add up to a total of nearly US$9.2 trillion over the next 44 years (2005/07-2050). This amount would be necessary to remain consistent with FAO's long-term outlook for global agriculture (World agriculture: towards 2030/50).

Broken down by type of investment, more than US$5.5 trillion or 60 percent of the total would be required to replace the existing capital stock (or new capital items that are being added and subsequently depreciated over the 44 year period to 2050); the rest, i.e. about US$3.6 trillion would need to be added to the existing capital stock to increase (nearly double) output and raise productivity. Broken down by activity, primary agriculture accounts for about US$5.2 trillion of the total, while the remaining US$4.0 trillion is absorbed by downstream needs (processing, transportation, storage, etc.). Within primary agriculture, mechanization accounts for the single biggest investment item (25 percent) followed by expansion and improvement of irrigation (nearly 20 percent). Broken down into annual amounts, the cumulative investments result in yearly averages of about US$210 billion gross and US$83 billion net, respectively. All estimates, gross and net, cumulative and annual, are in constant 2009 dollars.

A striking feature of the outlook is that the annual net additions to the capital stock (growth investments) exhibit a noticeable decline over time, which results in a slow-down in the annual net capital requirement. These net investments account for 55 percent of the total at the beginning of the projection period and for merely 30 percent towards 2050. The change in net investments reflects a number of different factors. First and obviously, incremental production needs to decline alongside declining incremental needs. Partly offsetting this decline is a shift towards more capital-intensive forms of production with a growing replacement of labour by capital. A third, factor, again supporting the declining net capital needs is a somewhat higher overall efficiency of input use in the future.

Growth accounting results suggests that overall growth will be characterised by a growing substitution of labour with capital and moderate total factor productivity growth. There are, however, marked regional differences. In Latin America, for instance, growth will be capital and productivity-based, with negative labour contributions. In sub-Saharan Africa, by contrast, growth will be heavily labour and moderately capital based, with limited efficiency gains.

The analysis of performance indicators suggests that there are marked regional differences in the capacity of agriculture to generate incomes and reduce poverty. Projections for the gross value of production for instance suggest that revenues generated by an agricultural labourer in sub-Saharan Africa will rise only by 50 percent over the next four decades. The expected growth in food markets will not suffice to lift revenues significantly.

The analysis of expected revenues, capital stocks and land available per labourer suggests that too many people in sub-Saharan Africa will remain dependent on a labour-intensive, capital-saving form of small-scale agriculture, in which too many farmers will have too few resources and revenues to share. The poverty reduction potential in the projected revenue/capital stock trajectory in sub-Saharan Africa should thus be limited.

This poses questions as to what alternative income sources could be tapped. Emerging options include new opportunities that arise from higher energy prices and a production of bioenergy feedstocks; income opportunities from the provision of environmental services; or a greater export orientation of production. All three growth options call for a know-how and a capital-intensive form of agriculture and thus run counter to the factor endowment that characterises Africa's smallholder structure. One option to overcome these constraints would be through increased investments in resource-pooling institutions.

The available capital stock per worker was identified as an important explanatory variable for inter-regional differences in performance. A farmer in Latin America has on average 10 times more capital available than his colleague in sub-Saharan Africa. Behind the abstract aggregate of capital per farmer are a large range of tools and equipment that make agriculture in Latin America so much more productive than in Africa. It includes more and better mechanization, tractors, tillers and combines, irrigation, storage and processing plants, and other elements of an efficient downstream sector. Moreover, Latin American farmers have multiples of support capital in better infrastructure, research institutions, available roads, or electricity. Rural roads per hectare for instance amount to 0.017 km in Latin America compared to 0.007 km, i.e. less than half that distance in sub-Saharan Africa. Likewise, rural electricity supplies per worker are 50 times higher in Latin America compared to sub-Saharan Africa.

## INTRODUCTION

This paper is an interim report on ongoing work at FAO to estimate investment requirements in developing countries' agriculture. The estimates presented in the paper are far from final and the narrative of future trends and developments is far from complete. Estimates cover most capital items, without however singling out areas for public involvement, neither of domestic nor of foreign funding sources.

Nor has any attempt been made to gauge incremental investment needs required to attain certain development goals such as MDG-1 or the target set by the World Food Summit. This also means that important investment areas such as agricultural research or rural infrastructure are excluded. These will be covered in later work. Likewise, an item of major concern to public investment, namely 'ensuring access to food for the most needy' (e.g. through social safety nets)[3] is not dealt with here.

Instead, the estimates presented in this paper embody a broad range of capital items needed to achieve the 2030 and 2050 crop and livestock production levels in developing countries as foreseen in the baseline outlook of the latest FAO perspective study (FAO, 2006a). The majority of these capital items relate to primary agriculture. In addition, a number of activities covered relate to downstream industries of primary agriculture, notably various forms of processing, storage and marketing.

The net additions to and replacement of obsolete capital stocks make up total investment requirements. Traditionally, the lion's share of capital needs was covered by private farmers and by entrepreneurs in the related upstream and downstream industries (including capital outlays in non-monetized forms). Some capital items such as irrigation development, rural infrastructure and agricultural research, will require public intervention. However, no effort has been made to measure the needed or desired level of public sector engagement. This can vary widely across capital items and countries, and any quantitative assessment would need to start from a detailed and disaggregated basis. One such assessment is planned as a follow-up to this assessment. It will be based on the investment assessment and the baseline projections underlying this paper and will gauge the incremental public capital requirements needed to reach a more ambitious outcome/development goal, such as a complete eradication of hunger within a shorter time span.

## METHODOLOGY AND MEASUREMENT: WHAT HAS BEEN MEASURED, WHAT NOT, AND HOW

### Imputed versus actual

The basic goal of this assessment was to gauge the amount of capital that will be required to produce the total amounts of crops and livestock products projected in FAO's long-term outlook to 2030 and 2050, i.e. the hectares of land to be developed, to be irrigated, to be put under permanent crops; the numbers of tractors, combines, implements or merely handtools, the increases in livestock herds, sheds, etc. This means that all investments are imputed estimates, not necessarily actual investments. Likewise, capital stocks are imputed and not necessarily actual, ditto for changes in capital stocks, i.e. net investments and depreciation.

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[3] Accounting for over a fifth of the incremental annual public investment as estimated in the FAO (2003) Anti-Hunger Programme.

**Box 1: Past FAO estimates of investment requirements**

The 1981 publication "Agriculture: Toward 2000" (FAO, 1981) gave an estimate of average annual gross investment over the 20 year period 1980-2000 for 90 developing countries (excluding China) of US$69 billion in 1975 dollars, US$47 billion for investment in primary agriculture (of which about a third for investment in replacement) and US$22 billion for investment in supporting capital stock. Separate estimates are given for (net) investment in forestry and fisheries. These investment estimates refer to total investment required, i.e. the sum of private and public investment.

The 1988 FAO study "World agriculture: toward 2000" is an update of the 1981 study and follows the same methodology. For 93 developing countries (excluding China) the estimate of annual (average over the 17 year period 1982/84-2000) gross investment amounts to US$88 billion in 1980 dollars. Investments in primary agriculture are estimated at US$50 billion (nearly 60 percent for investment in replacement), and investment in supporting capital stock at US$38 billion. No estimates are given for investment in forestry and fisheries.

The investment estimates of the Technical Background document No 10 for the 1995 World Food Summit, "Investment in agriculture: evolution and prospects", were based on the FAO study Alexandratos, N. (1995), "World agriculture: toward 2010". The estimates given in this publication refer to the group of 93 developing countries and are those needed to achieve the production projections of the latter publication (i.e. the WFS target is not considered and 637 million people are left undernourished in 2010).

The estimate for annual (average over 1993-2013) gross investment in 1993 dollars is US$ 129 billion, of which US$86 billion in primary agriculture (US$61 billion for replacement) and US$43 billion in support (or post-production) investment. To this are added US$37 billion worth of investments in public support services (mainly technology generation and transfer) and rural infrastructure, two categories not covered in earlier studies. The total then amounts to US$166 billion of which about three-quarters (US$125 billion) is private and one-quarter (US$41 billion) is public investment.

The next FAO exercise giving investment estimates (of a slightly different nature) was: FAO (1999), "Investment in agriculture for food security: Situation and resource requirements to reach the World Food Summit objectives", CFS:99/Inf 7[4].

The estimates are an update of the 1995 estimates (still for developing countries only) but this time refer to what is needed to reach the WFS target of halving the number of undernourished people in 2015. They are: an annual (average over 2000-2015) gross investment in 1995 dollars of US$140 billion, of which US$93 billion (US$66 billion for replacement) in primary agriculture and US$47 billion in support (or post-production) investment. To this is added an US$40 billion of investment in public support services and rural infrastructure. The total amounts to US$180 billion.

The latest FAO publication giving investment estimates is FAO's (2003), "Anti-Hunger Programme". The estimates given refer to what is needed to reach the WFS target in 2015. They cover only investment incremental to expected future public investment. Annual (average over 2003-2015) investment in 2002 dollars of US$23.8 billion of which US$2.3 billion for productivity improvements, US$7.4 billion for natural resource development, US$7.8 billion for rural infrastructure, US$1.1 billion for knowledge generation and US$5.2 billion for ensuring access to food.

These imputed investments and capital stocks can differ from actual investments and capital stocks for a number of reasons. If, for instance, farmers work with excessively depreciated capital stocks (old tractors, tillers, threshers, sheds, etc.), actual capital stocks would be lower than the imputed ones and vice versa. Conversely, some investments may not entirely or not always translate into monetary expenditures. For instance, when a farmer builds a storage facility for his cereal crop or a shed for his grazing animals, these activities may not or not fully be reflected in the actual value of the capital stocks; they are, however, part of

[4] Also reported in: FAO (2001), "Mobilizing resources to fight hunger," CFS:2001/Inf. 7.

the imputed capital as they absorb resources with positive opportunity costs and reflect a shift away from consumption into investment.

As a consequence, the estimated investment numbers and capital stocks may not or not always correspond to those from other sources such as national accounts. While this means that deviations from actual capital stocks are unavoidable in the short-run, imputed and actual capital stocks and investment requirements should converge in the longer-run, at the latest after one full depreciation period of the item with the longest lifespan. The outlook to 2050 should thus be sufficiently long to ensure convergence. At any rate, the advantage of the calculation of imputed capital stocks is that the results are comparable across countries and over time.

## Investment areas and unit costs

In order to derive capital needs from production projections, changes in agricultural outputs were linked to 26 different capital items. For every capital item, specific unit costs and a specific lifetime and thus depreciation periods were chosen. The imputed values are obtained by multiplying the physical quantities (hectares, numbers, etc. in the base year and the years 2030 and 2050) with an average unit cost expressed in constant 2009 US dollars. While the calculations have been undertaken on the basis of 93 individual developing countries, specificity for unit costs and depreciation periods has been limited to regional averages. Of the 26 capital items, 14 relate to primary agriculture (including some non-conventional ones such as "establishment of permanent crops", "herd increases" and "working capital") and 12 related to the agricultural downstream sector (see Box 2 for a listing of the capital items).

Investment in agricultural downstream activities covers storage, processing and marketing of agricultural products. They are included for the sake of completeness although they may not always or entirely be attributable to agriculture and agricultural development. Not covered are investments related to manufacturing and distribution of agricultural inputs such as fertilizer. Likewise, expenditures in agricultural research could not be estimated as part of the investment requirements. For all investment items, both primary and downstream sectors, unit costs have been identified. Obviously, the absolute levels of the investment requirements are contingent on factors such as the assumed unit costs, the capital (input) absorbed per unit of agricultural activity or the assumed lifespan of a capital item[5].

## Depreciation and gross investment

The additions in the capital stocks between the base year (2005/07) and the years 2030 and 2050 amount to the cumulative net investment requirements over the projection periods. Subsequently, requirements for replacement investment are derived for the capital goods which must be replaced periodically. For each capital item a specific lifetime has been identified. For example, permanent crops are assumed to have a life span of 25 years, tractors one of 15 years, and so on. For many capital items replacement investments exceed net investments. Estimates for replacement investment are added to the net requirements to obtain estimates of gross investment (see Box 3 for a summary explanation).

**Box 2: List of capital items included**

***Crop production:***

- Development of arable land under crops
- Soil and water conservation
- Flood control
- Expansion and improvement of irrigation
- Establishment of permanent crops (citrus, other fruit, oil palm, coconuts, cocoa, coffee, tea and rubber)
- Mechanization (tractors and equipment)
- Other power sources and equipment (increase in number of draft animals; equipment for draft animals; handtools)
- Working capital (50 percent of the increase in the cost of fertilizer and seed)

[5] Investments in physical units are, in general, more robust than those in monetary terms as it proves difficult to assemble appropriate unit value costs for the various investment items.

***Livestock production:***

- Increase in livestock numbers (cattle and buffaloes, sheep and goat, pigs, poultry)
- Housing and equipment for commercial production of pigs and poultry
- Development of grazing land

***Downstream support services:***

- Investment in milk production, processing
- Investment in meat production, processing
- Dry storage (cereals, pulses, oilseeds, cocoa, coffee, tea, tobacco and sugar)
- Cold storage (bananas, fruits and vegetables, livestock products)
- Rural marketing facilities
- Assembly and wholesale markets for fruits and vegetables
- Milling of cereals
- Processing of oilseeds, sugar crops, fruits and vegetables
- Ginning of seed cotton
- Other processing

## Country coverage

Capital stock and investment calculations are performed for the 93 developing countries covered in the FAO 2006 study (see the list of countries in Annex 1; note that countries in transition in Central Asia are not included).

## Endogeneity and technology shifts

The projections of future investment needs are linked to and derived from the projections of 40 individual agricultural production activities, assuming certain technologies and/or complete technology packages (frontiers). Over an outlook horizon of more than 40 years, investments requirements will not only be defined by a given, current stage of technology, but also encompass shifts to new frontiers. Depending on factors such as the farm size or opportunity costs of farm labour, farmers will shift to new technology levels. While important, these shifts have not been taken into account in an explicit manner. Instead, links have been established indirectly by associating output levels (e.g. crop yields) with a certain package of input requirements; in many cases, this is done in a step-wise linear manner and is meant to emulate the shifts in technology. To make assumption more transparent and these technology shifts more explicit, future revisions therefore will attempt to include such frontier shifts directly, with links to changes in the overall level of development and/or farm size.

**Box 3: Derivation of investment requirement estimates**

The projections to 2050 cover 40 agricultural production activities (34 relating to crop production and 6 related to livestock production) in 93 developing countries. Each activity draws on a certain amount of current inputs and capital stock services.

For each of the 26 capital items distinguished, the value of capital stock, CS, is calculated for each year covered in the model (t = 2005/07, 2010, 2015, 2030 and 2050) multiplying the physical quantity, Q (hectares, numbers, etc.) with an average unit cost, P, expressed in 2009 US dollars.

For each capital item, the net investment in any year, $I_t^n$, is defined as the net increase in the value of capital stock over that year, or as the growth of capital stock, g, times capital stock, CS, at the beginning of the year. The growth rate is estimated as the annual growth of capital stock over the period preceding the year in question (except for the base year):

$$I_t^n = g_t \cdot CS_t \qquad (1)$$

Replacement investment in any year t is equal to the gross annual investment of L years earlier, where L is the economic life of the capital good in question. Gross annual investment, $I_t^g$, is defined as the sum of net annual investment and replacement investment in the same year:

$$I_t^g = I_t^n + I_{t-L}^g \qquad (2)$$

Equation (2) can be approximated as:

$$I_t^g = \frac{I_t^n}{1-(1+g_t)^{-L}} \quad (3)$$

Cumulative net investment $CI_t^n$ over any of the periods distinguished in the model (2005/07 to 2010, 2010 to 2015, 2015 to 2030 ad 2030 to 2050) is defined (and calculated) as the net increase in capital stock over that period:

$$CI_t^n = CS_t - CS_{t-1} \quad (4)$$

Cumulative gross investment is defined (and calculated) in a manner similar to annual gross investment:

$$CI_t^g = \frac{CI_t^n}{1-(1+g_t)^{-L}} \quad (5)$$

Total annual and cumulative net and gross investments are simply derived by adding up over the 26 capital items.

### Public and/or private

No distinction has been made with respect to the potential source of the required capital. Therefore, the amounts include all potential sources; that is private and public both of foreign and domestic provenance. The way capital stocks are financed currently suggests that the largest part of total investments comes from private domestic sources. And the selection of capital items in this assessment suggests that private sources (domestic and foreign) would be the prime source of capital, at least if it is assumed that public investments should be limited to activities where public goods are produced (hunger and poverty reduction, environmental sustainability, social cohesion, etc.). The public hand can play a role either in funding these investments directly or by helping link, pool and promote private flows. Typically, such investments include the creation and maintenance of infrastructure, large-scale irrigation schemes, or research and development of new crop varieties and animal breeds. Depending on the level of public engagement, these investments can help attract further private flows (crowding in) or, if too massive, replace private engagement (crowding out effects). Private public partnerships would aim at maximising the former and minimising the latter.

## THE RESULTS

### Projected capital stocks and investment needs

Provisional results for investment requirements for primary agriculture and its downstream industries in developing countries show that the total over the 44-year period 2005/07 to 2050 could amount to almost US$ 9.2 trillion (2009 dollars), 57 percent of which for primary agriculture and the remainder for support services (Table 1). Within primary agriculture, about a quarter of all capital needs stem from projected mechanization needs and almost a fifth (18.5 percent) from a further expansion and improvement of irrigation.

**Table 1: Cumulative investment over 2005/07 to 2050 in billion 2009 US$**

| | net | depreciation | gross |
|---|---|---|---|
| **Total for 93 developing countries** | **3636** | **5538** | **9174** |
| **total investment in primary production** | **2378** | **2809** | **5187** |
| **of which in crop production** | **864** | **2641** | **3505** |
| Land development, soil conservation and flood control | 139 | 22 | 161 |
| Expansion and improvement of irrigation | 158 | 803 | 960 |
| Permanent crops establishment | 84 | 411 | 495 |
| Mechanization | 356 | 956 | 1312 |
| Other power sources and equipment | 33 | 449 | 482 |
| Working capital | 94 | 0 | 94 |
| **of which in livestock production** | **1514** | **168** | **1683** |
| Herd increases | 413 | 0 | 413 |
| Meat and milk production | 1101 | 168 | 1269 |
| **total investment in downstream support services** | **1257** | **2729** | **3986** |
| Cold and dry storage | 277 | 520 | 797 |
| Rural and wholesale market facilities | 410 | 548 | 959 |
| First stage processing | 570 | 1661 | 2231 |

Broken down by type of investment, 60 percent or US$5.5 trillion will be needed to replace existing capital stocks, the other 40 percent or US$3.7 trillion would be growth investments and thus net additions to the existing capital stock. A detailed account of sector-specific investment projections is available in Annex 2.

The share of investments in primary agriculture is expected to fall in all regions, again at considerably different rates. Investments in downstream activities in turn rise in all regions. Perhaps surprisingly at first sight, the fastest growth in downstream activities is expected for sub-Saharan Africa, albeit from a relatively low absolute level. The region's food system is the least mature and growth reflects a gradual move away from a heavy reliance on primary production only. East Asia, by contrast, already has the most mature system, higher levels of grain, sugar, meat and milk processing and thus exhibits the smallest growth in non-primary growth, but at much higher absolute levels (Figure 1).

**Figure 1: Capital stocks in primary agriculture and downstream industries, sub-Saharan Africa and East Asia**

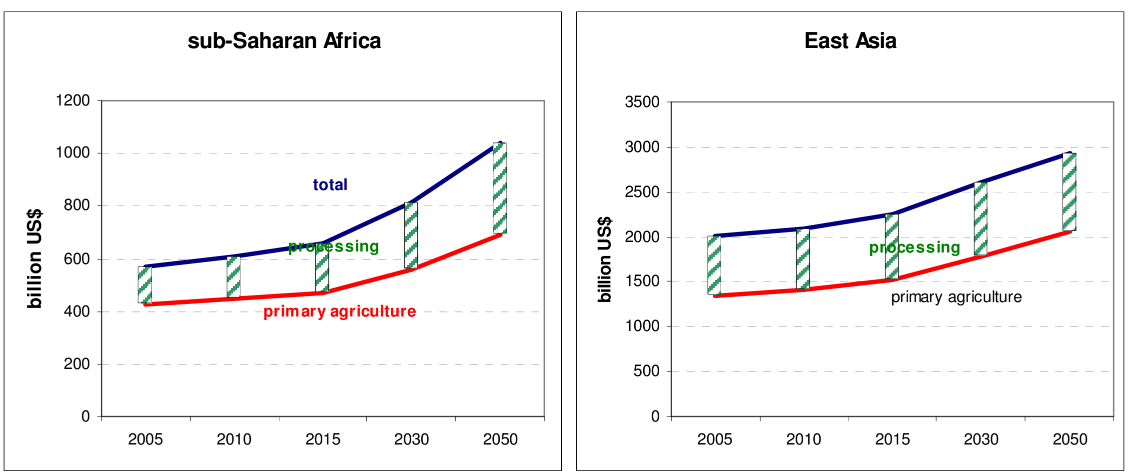
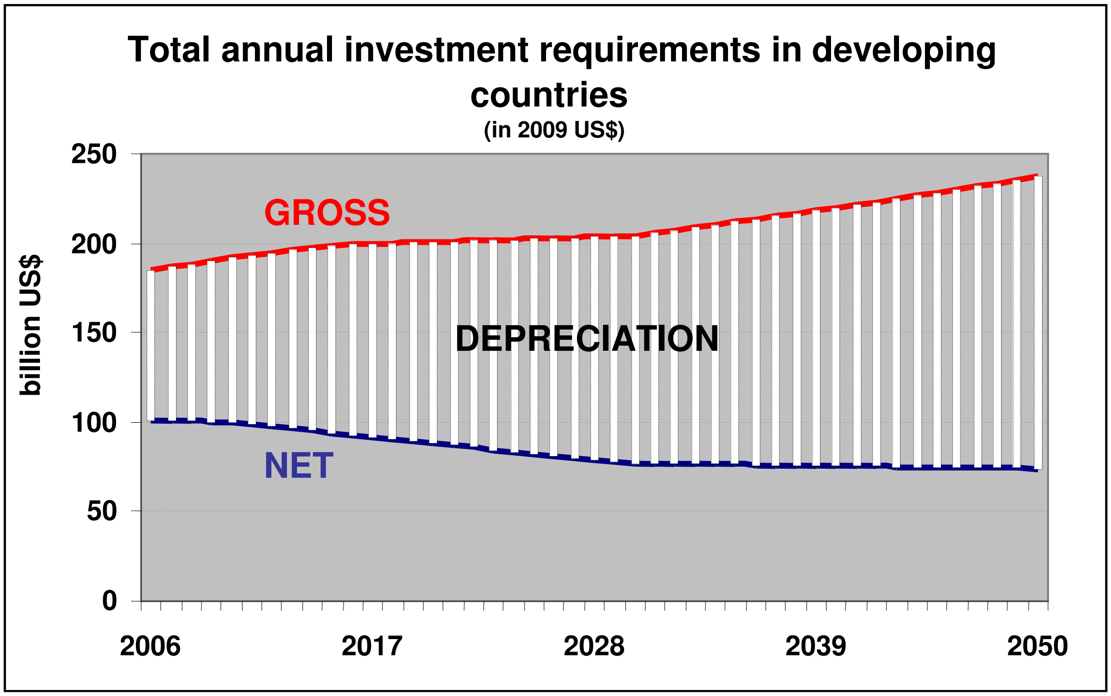


**Figure 2: Total annual (public and private) investment requirements in developing countries**




A striking feature of the outlook is that the annual net additions to the capital stock (growth investments) exhibit a noticeable decline over time and result in a slow-down in the annual net capital requirement. "Growth" investments account for 55 percent of the total at the beginning of the projection period and for merely 30 percent towards 2050 (Figure 2). For the aggregate of the developing countries as a whole, this reflects a number of different factors.

First, and obviously, a declining incremental production need (Table 2), driven by declining population growth and growing satiation levels of per capita consumption for food and fibre, also drive down incremental investment needs. For developing countries as a whole, overall agricultural production grew at a rate of 3.5 percent over the last 46 years and is expected to grow at a rate of less than half that level over the next 44 years. While the decline in production dynamics supports the projected slow-down in capital needs, there will be a countervailing shift towards more capital-intensive forms of production and a growing replacement of labour by capital. This explains the more moderate decline in incremental capital needs than is suggested by the expected levelling of output growth. And third, there is the impact of a change in the overall efficiency of input use, or total factor productivity (TFP). This is derived as the residual element of output growth that cannot be explained by growing input use, i.e. neither by changes in labour nor by changes in capital and land. While no TFP accounting is available for the past, future TFP growth is expected to be moderately positive for developing countries as a whole, albeit at rates of considerable difference across regions.

**Table 2: Growth rates of agricultural production, percent p.a.**

| | 1961-2007 | 1981-2007 | 1991-2007 | 2005/07-2030 | 2030-50 | 2005/07-2050 |
|---|---|---|---|---|---|---|
| Developing countries | 3.5 | 3.6 | 3.5 | 1.8 | 1.1 | 1.5 |
| idem, excl. China and India | 3.0 | 3.0 | 3.1 | 2.1 | 1.4 | 1.8 |
| sub-Saharan Africa | 2.6 | 3.3 | 3.1 | 2.7 | 1.9 | 2.3 |
| Near East/North Africa | 3.0 | 2.7 | 2.5 | 2.1 | 1.3 | 1.7 |
| Latin America and Caribbean | 3.0 | 3.0 | 3.4 | 2.1 | 1.2 | 1.7 |
| South Asia | 2.8 | 2.8 | 2.4 | 2.0 | 1.3 | 1.6 |
| East Asia | 4.3 | 4.5 | 4.3 | 1.3 | 0.6 | 1.0 |

For the aggregate of all developing countries, the relative importance of these factors (from 2005 to 2050), renders the following shares: (net) change in capital: +71 percent, in agricultural labour: -16 percent, in land use: +25 percent, and in total factor productivity: +20 percent[6]. This suggests a moderate decline in the role of labour inputs and an equally moderate replacement of labour with capital. Obviously, the aggregate hides vastly divergent developments in the various regions and for instance a much larger capital/labour substitution in Latin America (capital: +62 percent, labour: -73 percent, land: +49 percent, TFP: +62 percent) and no such shift at all in sub-Saharan Africa (capital: +48 percent, labour: +59 percent, land: +28 percent, TFP: -35 percent). Colloquially put, sub-Saharan Africa would continue to grow by "transpiration", while Latin America could further grow by efficiency gains or "inspiration".

A breakdown by region suggests that Asia would account for the largest part of global investment needs (57 percent); China and India alone account for some 40 percent. Latin America would absorb about 20 percent and sub-Saharan Africa and the Near East and North Africa region for the remaining 23 percent of capital needs (Table 3). Asia's high share reflects the region's large agricultural base, its high overall output and its relatively capital-intensive forms of agricultural production (irrigation, mechanization, terracing, etc.). Growth rates for Asia, however, would be more modest. This is in stark contrast to sub-Saharan Africa, where the overall level of investment requirements is expected to be relatively modest, reflecting the region's generally labour-intensive, capital-saving forms of production, while growth rates are projected to be higher, reflecting a very gradual shift to a more capital-intensive form of agriculture and moderately rising per capita production levels driven by a doubling of its population and consumer base.

**Table 3: Cumulative investment over 2005/07 to 2050 by region**

| | net | depreciation | gross | | | | |
|---|---|---|---|---|---|---|---|
| | | | crop production | livestock production | support services | total | share in total |
| | billion 2009US$ | | | | | | % |
| 93 developing countries | 3636 | 5538 | 3505 | 1683 | 3986 | 9174 | 100 |
| excl. China and India | 2427 | 3169 | 2184 | 966 | 2447 | 5596 | 61 |
| sub-Saharan Africa | 479 | 462 | 319 | 178 | 444 | 940 | 10 |
| Latin America /Caribbean | 842 | 962 | 528 | 316 | 960 | 1804 | 20 |
| Near East / North Africa | 451 | 742 | 619 | 152 | 422 | 1193 | 13 |
| South Asia | 843 | 1444 | 1024 | 368 | 894 | 2286 | 25 |
| East Asia | 1022 | 1928 | 1015 | 669 | 1266 | 2950 | 32 |

Broken down into annual instalments over the 44-year outlook period, the total gross needs of US$9.2 trillion amount to annual capital requirements of nearly US$210 billion. Over time, a larger share of the net investment requirements would occur in the early years and decades of the outlook, reflecting, inter alia, higher incremental investment needs in these years. Thereafter the slowdown in production growth would also be reflected in a levelling-off of incremental investment needs. This "frontloading" effect could have important policy implications and lend itself to important policy messages.

As indicated, this assessment does not provide an assessment of public vs. private financing, neither from domestic nor from foreign sources. If current private/public shares were to be applied to the projections,

[6] The underlying growth accounting approach applied here assumes a uniform, constant real wage across all income strata.

70 percent or US$150 billion of the US$210 billion would come from private sources, the remaining 30 percent or US$60 billion would have to be provided by public sources, both foreign (ODA) and domestic.

## HOW RESOURCES WILL BE PUT TO WORK: PERFORMANCE INDICATORS FOR AGRICULTURAL PRODUCTION, CAPITAL STOCKS, LABOUR AND LAND

### How much will be produced by whom?

In 2005, East Asia alone accounted for nearly half of the developing world's agricultural output. Measured in ICPs[7], US$554 billion dollars came from that region and it was followed by Latin America and South Asia which produced an annual agricultural output of US$210-15 billion each and the Near East/North Africa region and sub-Saharan Africa with a mere US$95 billion and US$98 billion respectively per year (Table 4).

A look at the long-term growth path to 2050 suggests a dynamic that is quite different from the current rates and levels. Sub-Saharan Africa, currently the region with about lowest agricultural output, is expected to show the fastest growth and could nearly triple its production to US$263 billion by 2050. East Asia, by contrast, currently the largest producer, will see an increase in output by merely 53 percent (Table 4). By large measure, this reflects the fact that sub-Saharan Africa has to meet the food needs for the largest population increase of all regions and will do so from its own agricultural production base. East Asia by contrast will only see a very modest overall growth in its population to 2050 falling to zero growth between 2030 and 2050. Moreover, the region has already attained relatively high per capita consumption levels (2870 kcal/person/day in 2000) which will rise only moderately to levels somewhat above 3200 kcal/person/day. It will, just like sub-Saharan Africa, feed its population from its own agricultural resources, with self-sufficiency declining only very moderately; in fact, the only region that is expected to step up production significantly beyond its own needs is Latin America with self-sufficiency rates projected to rise from 118 percent to 130 percent; Latin America will thus cover the moderately growing deficits of all other regions.

**Table 4: Gross value of agricultural production by region (billion 2004/06 ICP$)**

| | 2005 | 2030 | 2050 | 2050/2005 |
|---|---|---|---|---|
| Developing countries | 1172 | 1784 | 2207 | 1.88 |
| sub-Saharan Africa | 98 | 182 | 263 | 2.69 |
| Latin America and Caribbean | 210 | 343 | 436 | 2.08 |
| Near East / North Africa | 95 | 155 | 200 | 2.11 |
| South Asia | 216 | 356 | 459 | 2.12 |
| East Asia | 554 | 748 | 848 | 1.53 |

In order to meet these production increases, the various regions will have to put more money to work in agriculture, mobilize more capital, land and labour. How much more resources the various regions will commit, what role incremental capital, land and labour will play will be discussed in the next section. The starting point for this analysis is the expected output per person which will serve as the basis for the discussion of how efficiently land, labour and capital will be used. The latter will be based on an outlook for labour and capital intensity of production and explore the scope and limits of agriculture to create incomes and help reduce poverty.

[7] ICP or "international commodity prices" are used in order to avoid the use of exchange rates for obtaining country aggregates and to facilitate international comparative analysis of productivity. These "international prices", expressed in so-called "international dollars", are derived using a Geary-Khamis formula for the agricultural sector. This method assigns a single "price" to each commodity. For example, one metric ton of wheat has the same price regardless of the country where it was produced.

### How much output per person?

Probably the most important indicator[8] from a developmental perspective is the evolution of agricultural output per person employed in agriculture (per capita gross value of production, AgGVP/PC). It is a first proxy for how much revenue people employed in agriculture generate and how revenues will evolve over the long-run to 2050. It can also provide hints as to how big the contribution of agriculture to overall poverty reduction will be and how rapid the agricultural transformation is likely to evolve.

A first inspection of the levels and trends of output per labourer across regions reveals vastly divergent trends (Table 5). In 2005, by far the highest level of agricultural output per person was attained in Latin America and, despite the high initial levels, no slowdown in growth per agricultural labourer is expected for the region. On the contrary, agricultural output per person is projected to rise faster than in any other region and nearly quadruple to US$18,173 per person by 2050. On the other end of the spectrum is sub-Saharan Africa, where output per agricultural labourer is the lowest today and will remain the lowest by far over the next decades. In fact the gap to all other regions is even expected to widen as AgGVP/PC is expected to grow by less then 50 percent in 45 years.

**Table 5: Gross value of production per agricultural labourer (2004/06 ICP$ per person)**

| | 2005 | 2030 | 2050 | 2050/2005 |
|---|---|---|---|---|
| Developing countries | 882 | 1319 | 1844 | 2.09 |
| sub-Saharan Africa | 475 | 587 | 700 | 1.47 |
| Latin America and Caribbean | 4993 | 10405 | 18173 | 3.64 |
| Near East / North Africa | 1827 | 3157 | 4888 | 2.68 |
| South Asia | 575 | 836 | 1230 | 2.14 |
| East Asia | 845 | 1398 | 2221 | 2.63 |

This raises the question as to what forces drive these divergent regional trends and what the different paths mean for poverty reduction through agriculture. The first question can only be answered by analysing the trends in the underlying variables. The two factors involved are obviously trends in the overall value of output on the one hand and the evolution of the agricultural labour force on the other.

**Table 6: Aggregate self-sufficiency ratios (in percent) by region**

| | 2005 | 2050 |
|---|---|---|
| Developing countries | 99 | 99 |
| sub-Saharan Africa | 97 | 95 |
| Latin America and Caribbean | 118 | 130 |
| Near East / North Africa | 79 | 78 |
| South Asia | 99 | 98 |
| East Asia | 94 | 91 |

Growth in overall agricultural output will be the highest in sub-Saharan Africa. As discussed above, this reflects high growth in consumption and the fact that much of the added needs are expected to be met by domestic production. Self-sufficiency will decline only moderately from 97 percent in 2005 to 95 percent in 2050 (Table 6). Output will also rise in Latin America, albeit less rapidly and predominantly for export markets to make up for the slightly rising deficits of other regions. That means that the difference in the growth of output per worker is almost entirely due to the second factor, i.e. the changes in the agricultural labour force. In fact, the agricultural labour force of sub-Saharan Africa is projected to nearly double to 2050, while it will fall to nearly half in Latin America to 24 million (Table 7).

The mere numerical description of these trends does not allow to draw any inferences on the desirability of the associated development paths. What can be said, however, is that even the near tripling of agricultural output in sub-Saharan Africa will not suffice to make a significant difference in revenues per person left working in agriculture. When combined with the outlook for capital stocks (Table 8) and the land available per labourer (Table 9), it can also be said that too many people will remain dependent on a labour-intensive,

[8] Ideally, performance should be measured as gross margins (returns on variable costs) or net margins (returns on total costs) of production; this however would require a complete accounting for variable and fixed costs of production.

capital-saving form[9] of small-scale agriculture. The poverty reduction potential of this form of agriculture should remain limited by the very virtue that too many farmers will have too few revenues to share.

**Table 7: Agricultural labour force (millions) by region**

| | 2005 | 2030 | 2050 | 2050/2005 |
|---|---|---|---|---|
| Developing countries | 1,330 | 1,353 | 1,197 | 0.90 |
| sub-Saharan Africa | 206 | 310 | 376 | 1.83 |
| Latin America and Caribbean | 42 | 33 | 24 | 0.58 |
| Near East / North Africa | 52 | 49 | 41 | 0.79 |
| South Asia | 376 | 426 | 373 | 0.99 |
| East Asia | 655 | 535 | 382 | 0.58 |

Source: FAO Statistics Division

This is not to suggest that poverty reduction efforts and strategies should ignore small-scale agriculture. On the contrary, the fact that more than 70 percent of the poor reside in rural areas and most depend on small-scale agriculture suggests that poverty reduction strategies have to start from and fully embrace small scale farmers; but while a smallholder structure is the starting point for poverty reduction, it cannot be an objective in its own right, particularly in sub-Saharan Africa. For one thing, the expected growth in its domestic food markets is too limited to engender much improved incomes for a growing number of farmers; for another, agricultural export markets would remain elusive for an under-capitalised form of small-scale agriculture. If the market potential is limited to the food needs, new markets (e.g. energy markets), new non-market income possibilities (payments carbon offsets, climate change mitigation programmes, payment schemes for environmental services) or strategies for a complete exit from agriculture need to be found to generate income possibilities for its young and rapidly growing labour force.

But neither will the poverty reduction potential be significant in Latin America's large scale agriculture, at least in absolute terms. There are simply too few people remaining in the sector today to be brought out of poverty in the future. Those remaining in agriculture, however, will produce agricultural output large enough to make a living from it. In tandem with the rising output per person, Latin America will continue to pursue its current export-orientation. The overall rate of self-sufficiency is expected to rise from 118 percent to 130 percent by 2050 (Table 6). The region will continue and even expand its role as the world's agricultural power house and make up for the less dynamic growth in other regions.

An alternative way of attaining higher incomes and ensuring livelihoods, though not covered in this outlook, would be to raise revenues not covered in agricultural production. Options include revenues that could be raised through the provision of environmental services and in particular contributions to Green House Gas (GHG) abatement and the entry into the carbon market. It is important to note in this context that agriculture is, with a share of over 30 percent (including deforestation), not only one of the main sources of global GHG emissions but would also provide a significant potential for climate change mitigation. These funds could help farmers adopt carbon-saving production technologies, reduce carbon footprints of traditional technologies and, at the same time, increase productivity and profitability of agricultural production. Promising options include a shift to no-till and conservation agriculture, more efficient milk and ruminant meat production systems (FAO, 2006b) or a transition from paddy to upland rice production.

Another income alternative could arise from an increased production of agricultural feedstocks for the energy market. The energy market is so large that it would not be subject to demand constraints and would allow more farmers to draw revenues from otherwise increasingly saturated markets. For small scale farmers, bioenergy could help overcome the on farm power constraint, the factor that often limits agricultural productivity growth the most. For larger scale farmers, bioenergy offers a new potential to produce for a market that is in essence characterized by perfectly elastic demand and a market that will absorb any incremental production as long as agricultural feedstocks are competitive as input into the energy market, i.e. as long as energy prices are above parity prices in the energy market. In essence this necessitates high energy

[9] The capital stock available per worker will not increase in sub-Saharan Africa, while it will triple in Latin America (Table 8).

prices. The perfectly elastic demand also means that food prices will be determined by energy prices and that poor food consumers could be priced out of the food markets by less elastic energy consumers.

The success of such a diversification into new areas of agricultural activities will be contingent on whether smallholder agriculture has a comparative advantage for these new markets. Typically, smallholder agriculture is labour-intensive and capital-saving and in particular know-how deficient. Many of the emerging income options, by contrast, require know-how and capital and seldom unskilled labour. Tapping into carbon offset schemes under the "Clean Development Mechanism" (CDM), for instance, is mostly limited to large projects and large farmers and a large share of these CDM projects was granted to the large holdings or outright agricultural industries in Latin America. The administrative hurdles of such schemes are simply to onerous for smallholders to meet. Likewise, commercial bioenergy production is highly know-how and capital intensive; Brazilian ethanol production for instance has become more profitable as it became more labour-saving. The discrepancy between factor needs and factor endowments of smallholders means that they are unlikely to have a comparative advantage for these alternative income sources; in fact, their factor endowment is precisely the opposite of the factor requirements needed for such activities.

Options to overcome a lack of capital and know-how exist. One option would be to improve or create the institutional setting that allows a pooling of smallholder resources and create enough human and financial capital to overcome the resource limits. Co-operatives can play an important role in pooling resources; public investments can support and foster these efforts. There are numerous examples for successful resource pooling, particularly for new bioenergy projects. In Thailand, for instance, 4000 farmers have pooled resources in a co-operative to set-up a cassava based bio-ethanol project in the Chok Chai district of Nakhon Ratchasima; through the country's Agricultural Co-operative Federation they even established a joint-venture with a US-based energy company to overcome remaining capital constraints and attract the necessary know-how to operate a large-scale ethanol plant.

These examples suggest that the comparative disadvantage of small-scale farming for new market opportunities can be overcome and that the new markets could be tapped by small scale operators if their resources can be pooled. In turn this will require a strengthening of rural institutions and thus public investments. The greatest needs but also the greatest potentials for institutional improvements lie in sub-Saharan Africa. The quantitative assessments of the institution-related investments requirements will be provided in the companion paper to this assessment at a later stage.

### *Why will outcomes be so different? The correlates of success*

An important factor that helps explain difference in the output per worker is the ***capital stock per*** labourer available. Taking again the two extreme cases of Latin America and sub-Saharan Africa, the estimates summarized in Table 8 suggest that a farm worker in the former region has on average 10 times more capital available than his colleague in the latter. Behind the abstract aggregate of capital per farmer are a large range of tools and equipment that make agriculture in Latin America so much more productive than in Africa. It includes more and better mechanization, tractors, tillers and combines, irrigation, storage and processing plants, and other elements of an efficient downstream sector. And, while not included in the estimates, Latin American farmers have multiples of support capital in better infrastructure, research institutions, available roads and electricity. Equally important is reliability of these supplies, rendering fewer off-hours in terms of electricity supplies or irrigation water availability. Rural roads per hectare for instance amount to 0.017 km in Latin America compared to 0.007 km, i.e. less than half that distance in sub-Saharan Africa. Likewise, rural electricity supplies per worker are 50 times higher in Latin America compared to sub-Saharan Africa.

**Table 8: Capital stock per worker (in 2009 US$1000 per person)**

| | 2005 | 2030 | 2050 | 2050/2005 |
|---|---|---|---|---|
| Developing countries | 4.28 | 5.72 | 7.68 | 1.79 |
| sub-Saharan Africa | 2.78 | 2.62 | 2.77 | 1.00 |
| Latin America and Caribbean | 25.24 | 45.70 | 77.77 | 3.08 |
| Near East / North Africa | 11.61 | 17.33 | 25.41 | 2.19 |
| South Asia | 3.88 | 4.59 | 6.10 | 1.57 |
| East Asia | 3.06 | 4.87 | 7.67 | 2.51 |

The outlook to 2050 suggests that the inter-regional differences in capital stocks per worker are likely to become more pronounced. Capital stocks per worker will roughly double in East Asia, South Asia and the Near East and North Africa region while they will triple in Latin America and completely stagnate in sub-Saharan Africa. That means that by 2050 a worker in Latin America will have 28 times the capital available compared to his colleague in sub-Saharan Africa. These huge differences in capital intensity are at the heart of differences in the current output per worker and the divergent growth paths the two regions are expected to take.

As discussed above, a critical element in the divergent developments in labour productivity across regions is largely a reflection of the different developments in the agricultural labour force of the various regions. Latin America, for instance, will almost halve its labour force while sub-Saharan Africa will nearly double it. How important this effect is can be appreciated when agricultural output is related to land rather than labour (Table 9).

**Table 9: Harvested land per agricultural labourer (ha per person)**

| | 2005 | 2030 | 2050 | 2050/2005 |
|---|---|---|---|---|
| Developing countries | 0.69 | 0.75 | 0.90 | 1.30 |
| sub-Saharan Africa | 0.86 | 0.68 | 0.63 | 0.73 |
| Latin America and Caribbean | 3.47 | 5.53 | 8.62 | 2.49 |
| Near East / North Africa | 1.41 | 1.50 | 1.87 | 1.33 |
| South Asia | 0.60 | 0.56 | 0.65 | 1.08 |
| East Asia | 0.45 | 0.57 | 0.81 | 1.80 |

Output per hectare in Latin America is “only“ 2.5 times higher than in sub-Saharan Africa and indeed somewhat lower than in East Asia. But crucially, a worker in Latin America will crop twice as much land by 2050 while ***arable land available per labourer*** will further shrink in sub-Saharan Africa. This poses – once again - the question of how sustainable the outlook for sub-Saharan Africa’s is if it continues to be based on a farming system in which a limited resource base has to be shared with a rising number of resource users. Even if the basis of the argument is largely arithmetical, small scale agriculture is unlikely to provide much of a basis for widespread revenue generation and poverty reduction. It also poses the question as whether it needs to be combined with exit strategies that ensuring that those left in the sector have enough resources to generate sufficient income.

### *What bang for the buck? ICORs and investment rates in primary agriculture*

In an increasingly globalized world, private investors, development planners and policy makers alike are interested in identifying investment opportunities in agriculture at home and abroad. A broad and easy-to-calculate indicator that helps address this question is the Incremental Capital Output Ratio (ICOR)[10]. High ICORs suggest that increases in agricultural output require high investments and vice versa.

[10] It must be noted that the ICORs and investment rates used and presented here are only approximations and need to be qualified from a number of different perspectives. One factor is that numerator and denominator of ICORs and investment rates are based on different monetary definitions. The denominator of the investment rates for instance (the value of production) is based on 2004/06 ‘international commodity prices”, while the numerator (incremental capital stocks) is based on values in prices of constant 2009 US$; the same qualification is to be made in the calculation of the investment rates; another factor is that investments include non-monetary elements (such as an indigenous increase in the herd sizes or self-constructed farm buildings), which overstate investment rates and understates ICORs. However, as these shortcomings apply across all regions, they leave cross-regional comparisons unaffected and relative values consistent.

**Table 10: ICORs and investment rates in primary agriculture**

| | investment as share of AGVP | inputs as share of AGVP[11] | investment as share of AGDP | incremental capital output ratio (ICOR) |
|---|---|---|---|---|
| | average over 2005/07 to 2050 | | | |
| | percent | | | |
| Developing countries | 6.7 | 27 | 9.2 | 6.3 |
| excl. China and India | 7.5 | 27 | 10.3 | 5.8 |
| sub-Saharan Africa | 6.2 | 11 | 6.9 | 3.1 |
| Latin America /Caribbean | 5.7 | 29 | 8.0 | 4.8 |
| Near East / North Africa | 11.4 | 40 | 19.0 | 11.1 |
| South Asia | 9.0 | 28 | 12.5 | 7.2 |
| East Asia | 5.2 | 28 | 7.2 | 7.4 |

The comparison of the ICORs across regions (Table 10) suggests that changes in agricultural capital stocks are expected to render fairly different levels of agricultural output across the main developing regions. By far the highest ICORs (over 11) are projected for the Near East and North Africa (NENA) region, while by far the lowest ICORs (just over 3) are expected for sub-Saharan Africa. In both regions, the expected ICORs are consistent with current factor endowments and expected factor returns. High ICORs for the Near East and North Africa region reflect the fact that the region has already attained a high level of capital intensity and is left with few options to step-up production through an easy expansion of cropland or irrigation water use. In fact, the region has virtually exhausted its agricultural land base and is also approaching the limits of its renewable water resources. This makes further increases in production a capital-intensive endeavour and ultimately renders low returns on future additions to the existing capital stock. Extreme examples include agricultural production systems that operate on ground water mining or water supplies from energy-intensive desalinization plants; ICORs are particularly high where such investments were geared towards low value outputs such as cereals and other food staples. Such farming systems operate at unit production costs that often exceed international commodity prices by multiples and can only be sustained with exorbitantly high subsidies.

From a planning and policy perspective, this suggests that a further expansion of production in the NENA region has to be weighed against alternatives such as increased imports of agricultural goods or investments in foreign capital stocks and crop land. While the region has for long focused on imports, it recently also pursues the option to secure domestic supplies through foreign direct investment in other regions.

An inspection of the ICORs in other regions (Table 10) helps explain why much of these new investments are currently directed to sub-Saharan Africa. The low ICORs of just over 3 suggest that incremental capital invested in Africa's agriculture renders nearly four times the returns of investments in NENA. This is consistent with the fact that Africa's agriculture has abundant land and labour but suffers from a shortage of capital (working capital as well as fixed capital) that is needed to make the existing land and labour base more productive.

### *How will farm revenues fare relative to non-agricultural incomes?*

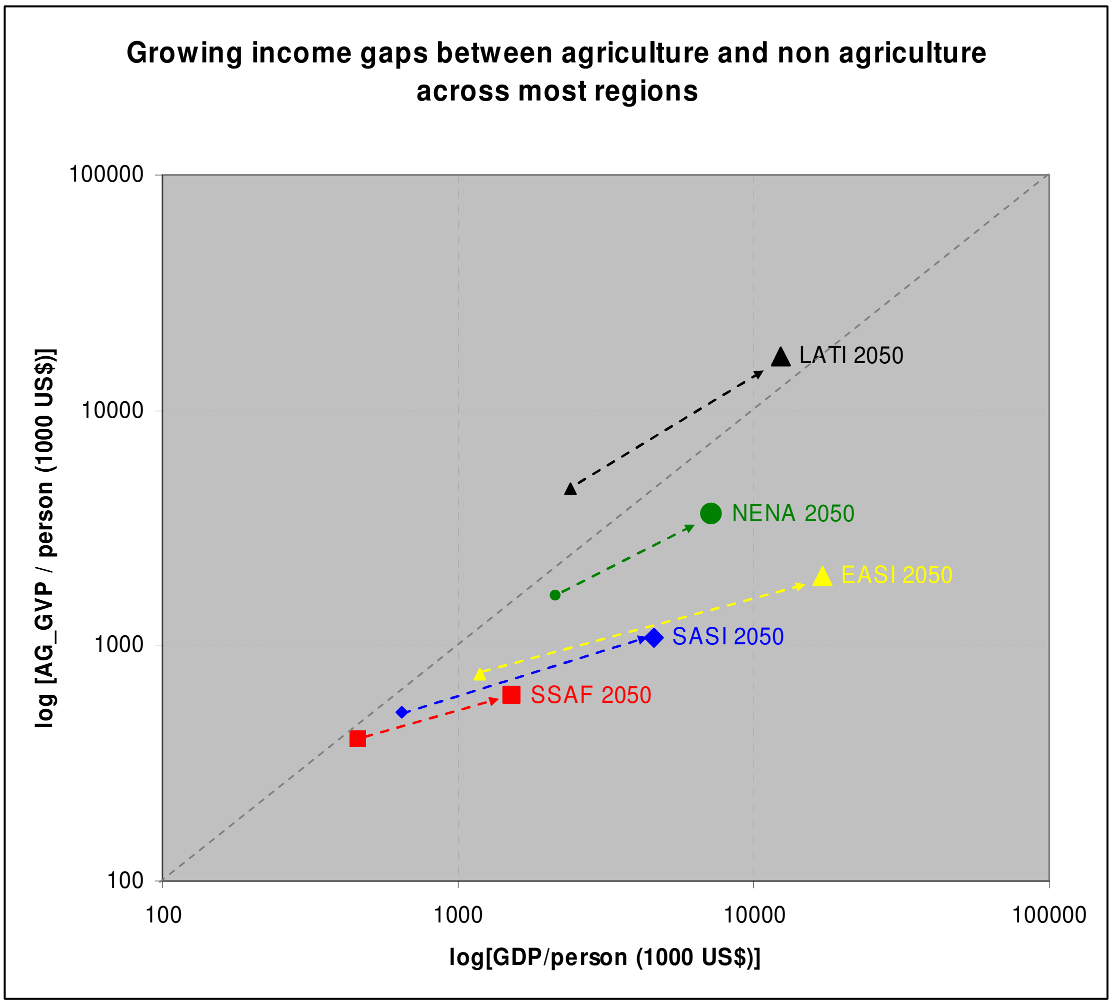
As outlined above, the trends in future farm revenues exhibit vast differences across regions and people dependent on agriculture in the various regions will see vastly different growth potentials for their agricultural income growth potentials. A crucial question that remains open is whether the projected revenue paths in agriculture are more or less favourable than those outside of agriculture or, more precisely, more or less favourable than those of the average income earner (agriculture and non-agriculture combined). The results of the comparison between agriculture and non-agriculture income trajectories are summarized in .

Figure 3 depicts three important features of the projected income trajectories for the various regions. First, the horizontal extension of the paths captures the projected income growth for each region. It suggests that income growth per person is expected to be much higher in East Asia than in any other region; compared to sub-Saharan Africa for instance, income growth is expected to be three times as high and overall the picture

[11] The value of inputs as a share of output are taken from Alexandratos (1988).

suggest a continuation of the growth patterns seen over the last three decades. Income growth is also projected to be high in South Asia, followed by Latin America and the Near East and North Africa region. The second feature is captured by the slope of the trajectories. The steeper the slope, the higher the agricultural growth prospects relative to overall growth. A slope steeper than the 45 degree diagonal denotes that agriculture outperforms the average of a region. Clearly, that is not expected for any of the regions; instead, trajectories are rather flat for all regions and move further away from an equal (45 degree) diagonal on the way to 2050. This unequal growth is particularly pronounced for all regional aggregates of sub-Saharan Africa and Asia. The third feature stems from the location of a trajectory above or below the diagonal. Locations above (below) denote whether agricultural incomes are above (below) average incomes, both for the starting and the end year. As can be seen immediately from , the only region where agricultural incomes are above average incomes is Latin America, while the reverse is the case for all other regions. And even for Latin America, it should be noted that vertical axis depicts agricultural GVP rather than agricultural GDP, i.e. agricultural incomes are overstated by the amount of working capital employed. Given the relative advanced stage of agriculture in Latin America, the effect of overestimation of incomes could be quite considerable; taking this into account, it is probable that in no region agricultural incomes are above average ones, neither in the base year nor in 2050.

**Figure 3: Regional income trajectories: agriculture vs. non-agriculture**




In summary, this means that the projected income trajectories suggest a largely negative outlook for agriculture. In no region will agricultural labourers be able to accomplish the same income growth as their peers outside of agriculture. The only exception is Latin America, where farm revenues are slightly above average incomes and where growth rates in farm revenues - on average – just match those of the region's economy. The outlook also suggests a growing divergence between agricultural and non-agricultural incomes and thus probably an even stronger concentration of poverty in rural areas. The results are likely to even understate the true agriculture vs. non-agriculture income gap for two reasons. First, agricultural income growth is compared to average income growth. Where agriculture accounts for a large share of the total economy, this would further increase the difference to non-agricultural incomes. Second, the population projections for agriculture are those for agricultural labour force, which is just a subset of the overall agricultural population. If agricultural incomes were to divided over the larger agricultural population, this would further widen the gap to non-agricultural incomes.

It must be emphasized here that these results are still highly preliminary; they need to be vetted further and confirmed by projections for AG-GDP, rather than those for AG-GVP only. The growing divergence may also bring to the fore a possible shortcoming of the underlying partial equilibrium approach. No doubt, past developments show that considerable and even growing rural – urban income differences can persist over extended periods of time, but a growing income divergence over more than four decades may become untenable and suggest that hitherto exogenous assumptions such as the projections for agricultural labour force or even population general projections may need to be endogenized. Rising income gaps would ultimately raise the pressure to leave rural areas (push) and attract cheap labour to more remunerative urban areas and non-farm environments (pull).

The prospect of a widening income gap between farm and non-farm incomes has also given rise to new initiatives to provide support to developing countries farmers. FAO is currently examining various possibilities of such support measures; the decisive criterion for these measures is that they help farmers to catch-up to average incomes attained in an economy or region without introducing new or augmenting existing measures that distort international competition, resource allocation and trade. Scope, options and limits of such measures will be discussed at the Summit on World Food Security in November 2009.

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## ANNEX 1: LIST OF COUNTRIES INCLUDED IN THE ANALYSIS

### Africa, sub-Saharan

Angola
Benin
Botswana
Burkina Faso
Burundi
Cameroon
Central Afr. Rep.
Chad
Congo
Côte d'Ivoire
Dem. Rep. of Congo
Eritrea
Ethiopia
Gabon
Gambia
Ghana
Guinea
Kenya
Lesotho
Liberia
Madagascar
Malawi
Mali
Mauritania
Mauritius
Mozambique
Niger
Nigeria
Rwanda
Senegal
Sierra Leone
Somalia
Sudan
Swaziland
Togo
Uganda
United Rep. of Tanzania
Zambia
Zimbabwe

### Latin America and Caribbean

Argentina
Bolivia
Brazil
Chile
Colombia
Costa Rica
Cuba
Dominican Rep.
Ecuador
El Salvador
Guatemala
Guyana
Haiti
Honduras
Jamaica
Mexico
Nicaragua
Panama
Paraguay
Peru
Suriname
Trinidad and Tobago
Uruguay
Venezuela

### Near East/North Africa

Afghanistan
Algeria
Egypt
Iran, Islamic Rep.
Iraq
Jordan
Lebanon
Libyan Arab Yam.
Morocco
Saudi Arabia
Syrian Arab Rep.
Tunisia
Turkey
Yemen

### South Asia

Bangladesh
India
Nepal
Pakistan
Sri Lanka

### *East Asia*

Cambodia
China
Dem. Rep. of Korea
Indonesia
Lao
Malaysia
Myanmar
Philippines
Rep. of Korea
Thailand
Viet Nam

## ANNEX 2: CUMULATIVE INVESTMENT REQUIREMENTS OVER 2005/07 TO 2050 IN BILLION 2009 US$ BY REGION

| | Sub-Saharan Africa | | | Latin America and Caribbean | | | Near East/North Africa | | | South Asia | | | East Asia | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Net | Depre-ciation | Gross | Net | Depre-ciation | Gross | Net | Depre-ciation | Gross | Net | Depre-ciation | Gross | Net | Depre-ciation | Gross |
| **Total** | 479 | 462 | 940 | 842 | 962 | 1804 | 451 | 742 | 1193 | 843 | 1444 | 2286 | 1022 | 1928 | 2950 |
| **total investment in primary production** | 272 | 225 | 496 | 479 | 365 | 844 | 300 | 470 | 771 | 585 | 808 | 1392 | 743 | 941 | 1684 |
| **of which in crop production** | 101 | 218 | 319 | 183 | 345 | 528 | 151 | 468 | 619 | 223 | 801 | 1024 | 206 | 809 | 1015 |
| Land development, soil conservation and flood control | 45 | 3 | 48 | 44 | 4 | 48 | 5 | 1 | 7 | 21 | 5 | 25 | 25 | 9 | 33 |
| Expansion and improvement of irrigation | 14 | 31 | 45 | 28 | 69 | 96 | 52 | 215 | 267 | 28 | 236 | 265 | 36 | 251 | 288 |
| Permanent crops establishment | 4 | 41 | 45 | 4 | 47 | 51 | 2 | 15 | 17 | 16 | 52 | 68 | 58 | 256 | 314 |
| Mechanization | 22 | 37 | 59 | 85 | 207 | 292 | 77 | 224 | 300 | 115 | 304 | 420 | 57 | 184 | 241 |
| Other power sources and equipment | 10 | 105 | 115 | 0 | 19 | 19 | 1 | 13 | 14 | 17 | 204 | 220 | 6 | 108 | 114 |
| Working capital | 6 | 0 | 6 | 22 | 0 | 22 | 15 | 0 | 15 | 26 | 0 | 26 | 25 | 0 | 25 |
| **of which in livestock production** | 171 | 7 | 178 | 296 | 20 | 316 | 149 | 3 | 152 | 362 | 6 | 368 | 536 | 133 | 669 |
| Herd increases | 67 | 0 | 67 | 85 | 0 | 85 | 37 | 0 | 37 | 96 | 0 | 96 | 128 | 0 | 128 |
| Meat and milk production | 104 | 7 | 110 | 211 | 20 | 231 | 112 | 3 | 115 | 265 | 6 | 272 | 408 | 133 | 541 |
| **total investment in downstream support services** | 207 | 237 | 444 | 363 | 597 | 960 | 150 | 272 | 422 | 258 | 636 | 894 | 279 | 987 | 1266 |
| Cold and dry storage | 41 | 37 | 78 | 96 | 88 | 184 | 20 | 46 | 66 | 55 | 109 | 164 | 65 | 240 | 305 |
| Rural and wholesale market facilities | 87 | 72 | 159 | 60 | 61 | 121 | 68 | 68 | 136 | 100 | 163 | 263 | 96 | 184 | 280 |
| First stage processing | 79 | 129 | 207 | 207 | 447 | 654 | 62 | 158 | 220 | 103 | 364 | 468 | 119 | 563 | 682 |

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# INVESTMENT IN DEVELOPING COUNTRIES' FOOD AND AGRICULTURE: ASSESSING AGRICULTURAL CAPITAL STOCKS AND THEIR IMPACT ON PRODUCTIVITY

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## EXECUTIVE SUMMARY

(1) The agricultural capital stock (ACS), measured as fixed assets in primary agriculture, has been growing steadily at the global level over the last three decades, although for most of this period at declining rates. Using a volume approach with country-specific constant values per asset to measure the ACS, the average annual rate of worldwide ACS growth fell from 1.1 percent between 1975 and 1990 to 0.5 percent between 1991 and 2007. This reduction was recorded in both developed and developing countries.

(2) A shift in the relative shares of capital formation between different regions and country groups appears to be taking place. The gap between higher rates of ACS growth in developing and lower rates in developed countries is falling. While the ACS shrinkage observed in the developed countries since the early 1990s countries has slowed, rates of ACS growth in the developing countries have remained positive but continued to fall.

(3) Annual rates of growth in the stock of improved agricultural land have been declining at global level. This may reflect at least in part a reduction in the willingness to invest in improving the productivity of the existing stock of land.

(4) The ACS has grown the least in countries with the highest prevalence and depth of hunger. In several of the least developed countries, in particular in sub-Saharan Africa and South Asia, the growth of the population active in agriculture has outstripped the rate of ACS growth.

(5) Government expenditure on agriculture is correlated with capital formation in a sample of developing countries. This correlation confirms the decisive role of public expenditure in creating an enabling environment in terms of infrastructure and sustainable access to natural resources. Public expenditure on agriculture can be an important ingredient in an investment climate conducive to agricultural development and the reduction of hunger.

(6) Between 1975 and 2007, annual total factor productivity growth in world agriculture was roughly 1.7 percent. This average masks important differences between regions, ranging from 2.1 percent in China and 1.7 percent in Transition countries to 1.4 percent in the rest of Asia, 1 percent in Latin America and 0.9 percent in Sub-Sahara-Africa. These differences between regions point to a substantial scope for further productivity growth.

(7) Government expenditure on agriculture has a significant positive impact on productivity in a sample of developing countries. All other things being equal, increasing government expenditure on agriculture by 10 percent leads to a 0.34 percent increase in a country's agricultural TFP. Foreign direct investment is also found to have a positive impact on productivity growth, but only in combination with efficient bureaucracy, a lack of corruption, and democratic political structures.

(8) The estimates of ACS levels and growth presented in this paper are based on two approaches which do not always produce the same results. Each of these approaches is characterised by important strengths and weaknesses. International Organizations such as the FAO should engage in a concerted and sustained effort to refine and reconcile estimates of ACS formation, including upstream and downstream sectors and rural infrastructure in developing countries.

## 1. INTRODUCTION

Between 1975 and 2005, global dietary energy supplies grew faster than the world population, which itself more than doubled. On global average, the food availability per person increased from 2400 to nearly 2800 kcal/person/day over those 30 years. In the developing countries the increase was even slightly steeper, from 2200 to 2600 kcal/person/day. This was a remarkable achievement of the global food and agriculture system, which was the result of significant investment and technical progress. As a result, the share of the world population with adequate access to food grew markedly. Most of the increases in consumption in developing countries were met by their domestic production, but food imports also expanded strongly.

Unfortunately, the growth in global per caput food supplies was not accompanied by a reduction in the number of the under-nourished. Although the prevalence of under-nourishment in the developing countries declined from 20 to 16 percent between 1990/92 and 2003/05, the absolute number of under-nourished individuals increased from 840 to nearly 850 million people. According to preliminary estimates by FAO, the high food prices in 2007 and 2008 may have driven up this number by a further 100 million. This rising trend could continue as a result of the global financial crisis.

As has been confirmed by research results and numerous high-level intergovernmental bodies, there is no lack of knowledge about how to make more progress towards the reduction of hunger and poverty (World Bank, 2008). Rapid progress in cutting the incidence of chronic hunger in developing countries is quite possible if political will is mobilized. Nearly three-quarters of the poor in developing countries live in rural areas. They depend on agriculture for their earnings, either directly or indirectly. According to FAO (2003), a twin-track approach is required, combining the promotion of quick-response agricultural growth, led by small farmers, with targeted programmes to ensure that the neediest people who have neither the capacity to produce their own food nor the means to buy it have access to adequate supplies. The two tracks are mutually reinforcing, since programmes to enhance direct and immediate access to food offer new outlets for expanded production.

Countries that have followed this approach have been comparatively successful in reducing the prevalence of undernourishment and achieving rapid and sustainable economic growth. In fact, a common feature of countries which were successful in reducing hunger and poverty is that they not only had higher overall rates of economic growth than the less successful countries, but that they achieved this higher growth through a relatively higher growth in agriculture. Moreover, these successful countries typically shared some other common features, namely absence of conflict and good governance, functioning markets, public investment in rural infrastructure and greater degree of integration in world markets than the less successful countries. Such success stories can be found in all regions (FAO, 2008).

This vital role of income earning opportunities in the rural areas of developing countries for success in improving the living conditions of the majority of the poor and hungry highlights the importance of investments in agriculture and rural development. In the World Food Summit Plan of Action of 1996, the Members of FAO expressed their commitment "to promote optimal allocation and use of public and private investments to foster human resources, sustainable food, agriculture, fisheries and forestry systems, and rural development, in high and low potential areas" (FAO 1996, Preamble). According to the plan, many developing countries needed "to reverse the recent neglect of investment in agriculture and rural development and mobilize sufficient investment resources to support sustainable food security and diversified rural development. A sound policy environment, in which such food-related investment can fulfil its potential, is essential. Most of the resources required for investment will be generated from domestic private and public sources. Governments should provide an economic and legal framework which promotes efficient markets that encourage private sector mobilization of savings, investment and capital formation. They should also devote an appropriate proportion of their expenditure to investments which enhance sustainable food security." (FAO 1996, Commitment Six).

Five years after the World Food Summit, FAO (2002) presented estimates of agricultural investments and capital stock in developing countries since 1975 and concluded that additional resources for promoting agricultural growth were especially needed in countries where undernourishment is more prevalent. Today, many of the problems recognized in 2002 are still not resolved. However, the pressures on world agriculture resulting from population growth, urbanization and growing demand for diversity, food quality and safety have grown, and new challenges for global agriculture have been added: climate change and variability, financial crisis, reduced availability of national and international finance, reduced public stock-holding, fluctuating energy prices and uncertain prospects for trade policy reforms.

Using various analytical tools, the following paper presents an update of earlier capital stock and investment estimates. We seek to contribute information needed to assess the extent to which developing countries have followed up on the commitments made more than a decade ago, and whether they are prepared to achieve food security for the future. We begin in section 2 with an overview of possible approaches to measuring investment and the agricultural capital stock. In section 3 the results of our estimates are presented and discussed. In section 4 we use our capital stock estimates to produce new estimates of total factor productivity (TFP) changes in agriculture in different regions of the world, contrasting these with earlier TFP estimates, and we explore the role that public expenditure on agriculture plays in both encouraging agricultural capital stock growth and TFP growth. Section 5 closes with a summary and outlook.

## 2. APPROACHES TO MEASURING INVESTMENT AND THE AGRICULTURAL CAPITAL STOCK

Comprehensive analysis of the agricultural capital stock (ACS) and investment needs in agriculture requires data on fixed and human capital on farm, as well as on fixed capital in infrastructure, in research and technology dissemination, and in the industries up- and down-stream from agriculture (input supply and agricultural processing) that have significant impacts on agricultural production. In addition to changes in physical and human capital, changes in natural capital can have major effects on agricultural performance. Sustainable land use practices such as conservation farming and integrated plant nutrition systems have contributed to considerable success in soil fertility management in many countries.

These are demanding requirements, which no existing source or compilation of data comes close to satisfying. Even if comprehensive data on all the above-mentioned components of the ACS were readily available for all countries or at least a representative sample, difficult issues of allocation/attribution would remain to be solved. For example, machinery might be used for farm and non-farm purposes (e.g. transportation); apparently unrelated upstream investments in flood and erosion control can have far-reaching impacts on farming downstream; investments in telecommunications infrastructure can have an important influence on market efficiency, production and welfare (Jensen, 2007). Measuring the ACS necessarily involves finding a compromise between a comprehensive coverage of countries over time – which is only possible for a relatively narrow definition of the ACS – and a comprehensive coverage of the relevant components of the ACS – which involves exhaustive work on a country-by-country basis.

To date, two main approaches to measuring the ACS and investments in agriculture have been employed. One is based on national accounts and captures a relatively broad set of ACS components, but only for a relatively narrow set of countries. The other is based on physical inventories contained in the FAOSTAT database which are available for essentially all countries over several decades, but which only cover a relatively narrow set of fixed assets in farming. Both approaches are employed in this study. In the following we first review earlier estimates of investment in developing country agriculture, before describing these two approaches and their strengths and weaknesses.

### 2.1 Earlier estimates of investment in developing country agriculture

Various attempts have been made to take stock of ACS formation in developing countries. FAO's last estimates of fixed capital in primary agriculture (FAO, 2002) covered the period 1975 to 1999 and revealed significant differences among countries. Specifically, the regions with the lowest prevalence of chronic undernourishment, in particular Latin America and the Near East and North Africa, were found to have a much higher ACS per agricultural worker ratio than the other developing regions. Not only was the level of capital intensity highest in regions with low prevalence of hunger, these same regions had also realized a significant increase in the ACS-labour ratio, whereas the other developing regions had stagnating or, in the case of Sub-Sahara-Africa, even declining capital intensities.

The same FAO publication also presented calculations of average labour productivity, measured as agricultural value added per agricultural worker. Not surprisingly, countries with low capital intensity in agriculture showed a low productivity per agricultural worker. In fact, the divergence of GDP per agricultural worker in country groups of different capital-labour ratios and hence different rates of hunger prevalence seemed to be very large and widening over time. Throughout the 1990s, the value added per worker in the group of countries with less than 2.5 percent of the population under-nourished was about 20 times higher than in the group with more than 35 percent undernourished.

Although equally relevant for the performance of the food and agricultural sector, capital formation in upstream and downstream sectors and in rural infrastructure has been much less frequently and completely documented. According to a tentative estimate published by FAO at the time of the World Food Summit in 1996, annual gross investments in primary agriculture of developing countries had amounted to approximately US$ 77 billion during the preceding ten to fifteen years (net investments: US$ 26 billion). Over the same period, annual gross investments in post harvest activities amounted to US$ 34 billion and public gross investments in rural infrastructure, agricultural research and extension US$ 29 billion. According to these estimates, therefore, capital formation in up- and downstream sectors and in rural infrastructure added up to almost the same total as investments in primary agriculture. By far the largest share of this off-farm investment (60 percent) took place in Asia during this period, while Latin America and the Caribbean accounted for 20 percent, and the Near East and North Africa and sub-Saharan Africa for 10 percent each. Unfortunately, the estimates published at this time did not allow a breakdown by country, nor have they been regularly updated. However, available evidence from various research projects shows that rural infrastructure is inadequate in many low income countries, particularly in much of Sub-Sahara Africa.

Although changes in natural agricultural capital cannot be inferred at the global level, some progress towards including the cost of natural capital depletion in national accounts has been made. Based on these efforts, the World Bank (2005a) has estimated the value of natural resources and concluded that in low-income countries, excluding the oil states, the share of the natural capital in total wealth is greater than the share of produced capital. Accounting for the value of depletion of this natural capital, so-called adjusted net national savings have been calculated as an indicator of real growth potential of a country. The results show that "net savings per person are negative in the world's most impoverished countries, particularly in sub-Saharan Africa". Depletion of soil quality is found to be a major loss in this context. It is alarming that this trend is identified in precisely those countries where agricultural development matters most for poverty and hunger reduction.

### 2.2. Estimating the agricultural capital stock with national accounts data

Crego et al. (1998) first used information on gross fixed capital formation in national accounts to generate ACS estimates for 57 countries between 1967 and 1992. We draw on an expanded version of this database produced by Anriquez and Daidone (2008) that contains more than 100 countries, but of which only 76 have agricultural gross fixed capital formation series long enough to allow for a reasonable estimate of physical capital stocks. This expanded database has been updated to cover up to 2002. As in Crego et al. (1998), data is not available in all years for all countries, but with some inter- and extrapolation a balanced panel from 1967 to 2003 can be generated for all 76 countries. Exceptions are the transition countries of Central and Eastern Europe, for which the series begin in 1990.

This dataset is generated based on the assumption that agricultural capital is composed of three components: 1) physical capital, 2) livestock, and 3) treestocks, which represent the value of the planted permanent crops. The physical capital series is constructed using time series of gross fixed capital formation in agriculture as published in national account statistics, and in a few instances using case studies that attempt to calculate these same series. The method used to estimate physical capital stocks is a variation of the perpetual inventory method (PIM). The PIM estimates current capital stocks by adding suitably depreciated investments from previous periods. Since capital stocks depreciate, only a finite history of investments in previous periods must be considered to determine current capital stocks.

In this study we assume a hyperbolic depreciation function (details in Crego et al. 1998), and also that the lifetime of each investment is normally distributed with a mean of 20 years and a standard error of 8 years. This means that with 95 percent probability each agricultural investment has a service lifetime between 4 and 36 years. To apply this methodology a long time series on gross investment is required. Where this was not available, previous gross investment levels where predicted (back-casted) using both agricultural value added (either that available or predicted using simple log trend), and the observed gross investment to agricultural value added ratio. All national capital stock series where estimated in constant national currency, and converted to current dollars using national deflators (to convert to series in current local currency) and the current exchange rates. The final comparable series in 1995 dollars were created by deflating the current dollars series using the US agricultural value added deflator.

The value of livestock is calculated using the stock numbers reported by FAOSTAT for different types of animals. Heads of livestock are valued using dollar prices which are estimated as regional weighted (by quantity) averages of implicit unit export prices, also obtained from FAOSTAT. Current dollar series are converted to constant 1995 dollars by deflating with the US agricultural GDP deflator.

Treestocks are valued as the present value of discounted future net revenues. First, net revenues are assumed to equal 80 percent of gross revenues which, in turn, are calculated per permanent crop as the product of yields and prices. Yields are calculated using area and total output data from FAOSTAT, while prices are 5-year moving averages of actual producer prices reported by FAOSTAT for each country. Two simplifying assumptions are made: first, that all permanent crops are at half of their productive life-spans; and second, that the lifespan of all permanent crops is 26 years. Future revenues are discounted using a 'real' rate of returns defined as the difference between the yields of ten 10-year US bonds and the inflation of the US GDP deflator for each period. The value of treestocks is converted to real 1995 dollars first by converting the series to current dollars using the period's exchange rate, and then by deflating this series with the US agricultural GDP deflator.

### 2.3. Estimating the agricultural capital stock using physical inventories in FAOSTAT

For many countries, national accounts data on gross fixed capital formation in agriculture is not available. As an alternative, the FAO Statistics Division in 1995 first compiled estimates of the ACS based on the physical stocks of various types of agricultural asset. For each asset, physical stocks were multiplied by a constant base-year unit price to produce a series of asset values over time. These values were subsequently aggregated over all assets to produce an estimate of the total ACS at constant prices.

Estimates of the ACS based on this method were first prepared at the regional level in 1995 as part of the World Agriculture Towards 2010 exercise (FAO 1995) for the period 1975 to 1995 and using 1990 US$ prices. These were subsequently updated in 2001 for the period 1975 to 1999, using a broader set of assets and 1995 US$ prices, and covering individual developing countries rather than only regional aggregates (FAO, 2002). These are the estimates of the ACS referred to in section 2.1 above. A further update to include the years to 2002 was prepared for FAO in 2006 (Barre, 2006).

We have updated the 1975-1999 estimates produced in 2001, and extended them to 2007.[1] The assets covered fall into four categories as outlined in Table 1 and are available for 223 countries and geographic entities.[2] To convert physical inventories into asset values, we use the 1995 unit asset prices that were compiled by the FAO (2002). These were drawn from a number of sources such as country investment project reports prepared by and for FAO, FAOSTAT data on purchase prices of means of production such as tractors, and unit trade values. For details on these unit prices and other aspects of the estimation, the reader is referred to FAO (2001a). Key issues include:

1) No data on physical stocks of hand tools are available, so the stock of these tools is estimated by multiplying the number of individuals active in agriculture in each country and year by a uniform estimate of 25$ worth of hand tools.
2) Unit land prices are estimated as the incremental values of development to make land suitable for crop production, to plant it to permanent crops, or to provide it with irrigation services.
3) No data on physical stocks of structures are available, so these are estimated as a function of the number of animals/poultry in each country and year.

[1] For some assets, FAOSTAT data is only available until 2005 or 2006. In these cases, the remaining years until 2007 have been extrapolated.
[2] The number of countries changes over time, for example due to the breakup of the Soviet Union. The FAOSTAT data includes entities such as Gaza and Greenland that are not independent countries.

**Table 1: Agricultural assets covered in the FAOSTAT measure of the ACS**

| Land development | Livestock | Machinery | Structures |
|---|---|---|---|
| • Arable land<br>• Permanent crops<br>• Irrigation | • Cattle<br>• Buffaloes<br>• Sheep<br>• Goats<br>• Pigs<br>• Horses<br>• Camels<br>• Mules and donkeys<br>• Poultry | • Tractors<br>• Harvesters<br>• Milking machines<br>• Hand tools | • For animals<br>• For poultry |

### 2.4 Strengths and weaknesses of the national accounts and FAOSTAT approaches

The national accounts-based estimates of the ACS have the important advantage of providing a considerably broader coverage of fixed capital in agriculture than the estimates based on FAOSTAT physical inventories. Furthermore, the use of the permanent inventory method coupled with consistent national accounts data on investments provides theoretically much sounder estimates of the value of the ACS in each year than the FAOSTAT approach. The use of constant prices in the FAOSTAT approach means that it essentially produces a volume index that does not account for the age of assets or quality improvements in assets over time (e.g. the fact that the average tractor made in 2005 can do more than the average tractor made in 1975, or that there have been genetic improvements in livestock over the same period).

The main disadvantage of the national accounts-based estimates is that they are only available for some countries. As might be expected, the OECD and other industrialised countries are well represented in the national accounts database, but this is not the case for developing countries (Table 2). For example, China is not included in the national account estimates, and only 10 countries in sub-Saharan Africa are, compared with 51 in the FAOSTAT physical inventories estimates.

**Table 2: Countries in the national accounts and FAOSTAT physical inventories databases by region**

| Region | Number of countries covered by... | |
|---|---|---|
| | National accounts estimates | FAOSTAT estimates |
| East Asia & Pacific | 4 | 42 |
| Europe & Central Asia | 6 | 25 |
| Latin America & Caribbean | 15 | 45 |
| Near East & North Africa | 7 | 22 |
| South Asia | 3 | 7 |
| Sub-Saharan Africa | 10 | 51 |
| High income OECD | 24 | 24 |
| High income non-OECD | 6 | 7 |
| Total | 75 | 223 |

This would not be of major concern if the national accounts database included a representative sample of all developing countries. However, there are indications that this is not the case. As is demonstrated below, there appears to be some selection bias in the sample of countries covered by the national accounts approach; the countries that are able to provide the required national accounts data appear to perform better on average in terms of investment in ACS. Hence, analysis based exclusively on the national accounts method might paint an overly positive picture of ACS levels and investments over time.

## 3. RESULTS: THE DEVELOPMENT OF THE AGRICULTURAL CAPITAL STOCK SINCE 1975

In the following sections, estimates of the ACS and its growth are presented for various groups and sub-groups of countries. In most cases the FAOSTAT physical inventories estimates are presented, because it is only possible to generate consistent aggregates over time with these estimates.

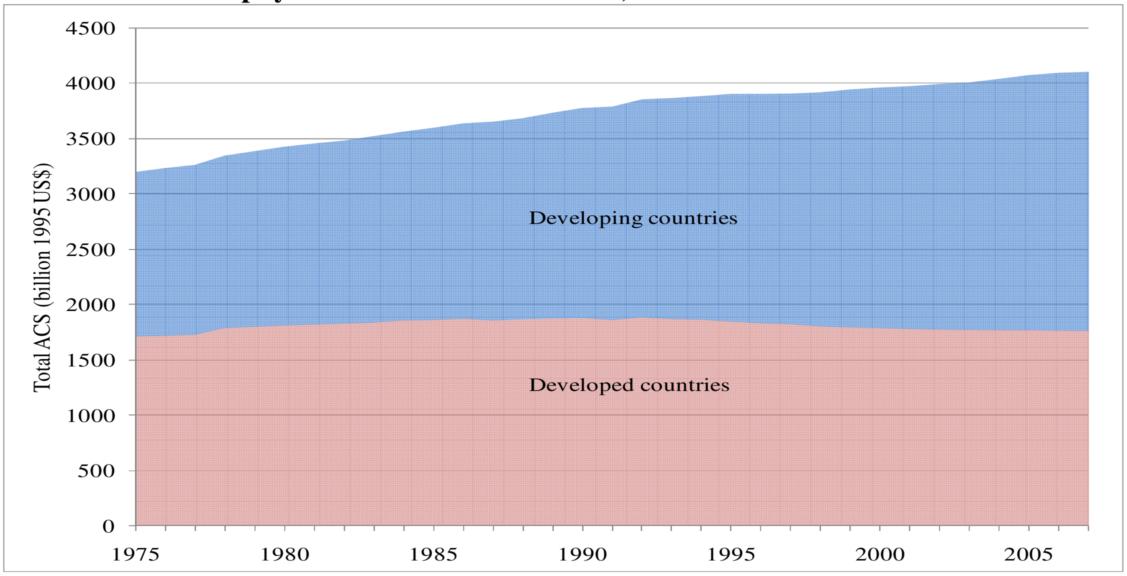
### 3.1. The development of the agricultural capital stock by region

Figure 1 displays the development of the total ACS between 1975 and 2007, worldwide and broken down into developed and developing countries. The worldwide rate of ACS growth (in other words net investment in the ACS) slowed around 1990; calculations confirm that the average annual rate of worldwide ACS growth fell from 1.1 percent between 1975 and 1990 to 0.5 percent between 1991 and 2007 (Further disaggregating these average annual growth rates reveals several interesting patterns. First, the reduction in the rate of ACS accumulation was sharpest in the second half of the 1990s, with ACS growth becoming strongly negative in developed countries and falling notably in developing countries (Figure 2). Since the beginning of the 2000s, the worldwide rate of ACS growth has increased again somewhat (from 0.32 to 0.52 percent per year), as the rate of ACS shrinkage in the developed countries has slowed. At the same time, rates of ACS growth in the developing countries have remained positive but continued to fall. Hence, the gap between rates of ACS growth in developing and developed countries has fallen from a high of just over 2 percent (1.27 percent vs. -0.76 percent) in 1995-99 to just over 1 percent (1.01 percent vs. -0.11 percent) in 2005-07 (see also The rapid reduction in rates of ACS growth in developed countries over the 1980s and 1990s was driven by episodes of significant disinvestment in different regions (**Error! Not a valid bookmark self-reference.**). In the 1980s, North America saw negative rates of ACS growth, and in the 1990s rates of growth in the ACS in Western Europe became negative, presumably due to in part to the effect of the 1993 so-called MacSharry reforms of the EU's Common Agricultural Policy. In the second half of the 1990s and into the 2000s, the ACS in the transition economies of Central and Eastern Europe shrank especially dramatically. In the developing countries, rates of ACS growth have been consistently positive across regions and sub-periods, with South Asia recording a sustained reduction in growth rates since the early 1990s.

Table 4). Since the data for 2007 are based on projections and data for 2008-09 are not yet available, it is not possible to determine what impact the food price crisis of 2007-08 had on rates of ACS accumulation in developing and developed countries.

Table 3). This slowdown was caused primarily by stagnating and then falling levels of ACS in the developed countries, although rates of ACS growth also fell in the developing countries over time. However, rates of ACS growth did not become negative in developing countries as they did for developed countries after 1990.

**Figure 1: The development of the agricultural capital stock (1975-2007, in billion 1995 US$ - FAOSTAT physical inventories estimates)**



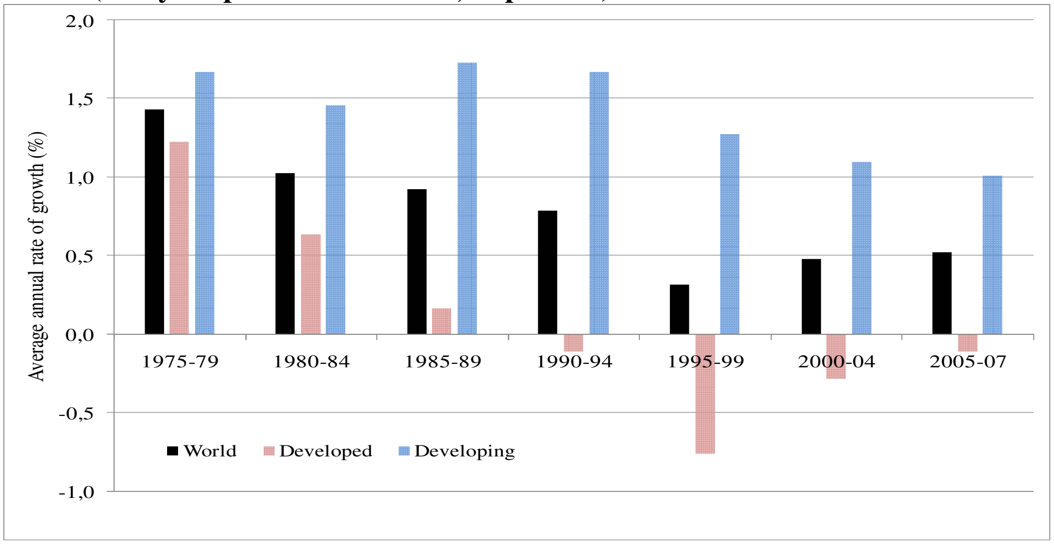

Further disaggregating these average annual growth rates reveals several interesting patterns. First, the reduction in the rate of ACS accumulation was sharpest in the second half of the 1990s, with ACS growth becoming strongly negative in developed countries and falling notably in developing countries (Figure 2). Since the beginning of the 2000s, the worldwide rate of ACS growth has increased again somewhat (from 0.32 to 0.52 percent per year), as the rate of ACS shrinkage in the developed countries has slowed. At the same time, rates of ACS growth in the developing countries have remained positive but continued to fall. Hence, the gap between rates of ACS growth in developing and developed countries has fallen from a high of just over 2 percent (1.27 percent vs. -0.76 percent) in 1995-99 to just over 1 percent (1.01 percent vs. -0.11 percent) in 2005-07 (see also The rapid reduction in rates of ACS growth in developed countries over the 1980s and 1990s was driven by episodes of significant disinvestment in different regions (**Error! Not a valid bookmark self-reference.**). In the 1980s, North America saw negative rates of ACS growth, and in the 1990s rates of growth in the ACS in Western Europe became negative, presumably due to in part to the effect of the 1993 so-called MacSharry reforms of the EU's Common Agricultural Policy. In the second half of the 1990s and into the 2000s, the ACS in the transition economies of Central and Eastern Europe shrank especially dramatically. In the developing countries, rates of ACS growth have been consistently positive across regions and sub-periods, with South Asia recording a sustained reduction in growth rates since the early 1990s.

Table 4). Since the data for 2007 are based on projections and data for 2008-09 are not yet available, it is not possible to determine what impact the food price crisis of 2007-08 had on rates of ACS accumulation in developing and developed countries.

**Table 3: Average annual rates of ACS growth before and after 1990 (percent)**

| | **1975-1990** | **1991-2007** |
|---|---|---|
| World | 1.11% | 0.50% |
| Developed countries | 0.60% | -0.34% |
| Developing countries | 1.66% | 1.23% |

**Figure 2: Average annual rates of growth in the ACS in developed and developing countries (five-year periods since 1975, in percent)**




The rapid reduction in rates of ACS growth in developed countries over the 1980s and 1990s was driven by episodes of significant disinvestment in different regions (**Error! Not a valid bookmark self-reference.**). In the 1980s, North America saw negative rates of ACS growth, and in the 1990s rates of growth in the ACS in Western Europe became negative, presumably due to in part to the effect of the 1993 so-called MacSharry reforms of the EU's Common Agricultural Policy. In the second half of the 1990s and into the 2000s, the ACS in the transition economies of Central and Eastern Europe shrank especially dramatically.[3] In the developing countries, rates of ACS growth have been consistently positive across regions and sub-periods, with South Asia recording a sustained reduction in growth rates since the early 1990s.

**Table 4: Average annual rates of growth in the ACS in regions of the world (five-year periods since 1975, in percent)**

| **Region** | **1975-79** | **1980-84** | **1985-89** | **1990-94** | **1995-99** | **2000-04** | **2005-07** | **1975-07** |
|---|---|---|---|---|---|---|---|---|
| *World* | *1.43* | *1.03* | *0.93* | *0.79* | *0.32* | *0.48* | *0.52* | *0.78* |
| *Developed* | *1.23* | *0.64* | *0.17* | *-0.11* | *-0.76* | *-0.28* | *-0.11* | *0.09* |
| N. America | 1.00 | -0.16 | -0.23 | 0.05 | 0.14 | -0.12 | 0.02 | *0.08* |
| W. Europe | 0.93 | 0.74 | 0.06 | -0.50 | -0.27 | -0.14 | -0.10 | *0.09* |
| Oceania | -0.84 | 0.24 | 0.51 | -0.17 | -0.54 | 0.49 | 0.42 | *0.02* |
| Transition | 2.03 | 1.55 | 0.62 | 0.07 | -2.77 | -0.71 | -0.31 | *0.02* |
| *Developing* | *1.67* | *1.46* | *1.73* | *1.67* | *1.27* | *1.10* | *1.01* | *1.43* |
| Latin A. & Caribbean | 2.15 | 1.40 | 1.76 | 1.40 | 0.39 | 1.16 | 0.22 | *1.24* |
| Near East & N. Africa | 0.93 | 1.76 | 1.99 | 1.87 | 0.71 | 0.93 | 0.99 | *1.34* |
| Sub-Saharan Africa | 1.68 | 1.42 | 1.23 | 1.86 | 1.65 | 1.64 | 0.96 | *1.52* |
| East & Southeast Asia | 1.75 | 1.37 | 2.04 | 1.80 | 1.86 | 1.35 | 1.73 | *1.70* |
| South Asia | 1.61 | 1.49 | 1.19 | 1.42 | 1.22 | 0.34 | 0.32 | *1.11* |

The consistently positive rates of ACS growth by developing country region in The rapid reduction in rates of ACS growth in developed countries over the 1980s and 1990s was driven by episodes of significant disinvestment in different regions (**Error! Not a valid bookmark self-reference.**). In the 1980s, North America saw negative rates of ACS growth, and in the 1990s rates of growth in the ACS in Western Europe became negative, presumably due to in part to the effect of the 1993 so-called MacSharry reforms of the EU's Common Agricultural Policy. In the second half of the 1990s and into the 2000s, the ACS in the transition economies of Central and Eastern Europe shrank especially dramatically. In the developing

[3] The drop in the rate of ACS accumulation in developed countries is also at least partly due to improvements in input quality, which the FAOSTAT-based estimates do not pick up. See section 3.5.

countries, rates of ACS growth have been consistently positive across regions and sub-periods, with South Asia recording a sustained reduction in growth rates since the early 1990s.

Table 4 mask important changes in the availability of ACS per worker. In sub-Saharan Africa and South Asia, the growth of the population active in agriculture has outstripped the rate of ACS growth, leading to average annual reductions in the ACS per worker in agriculture of 0.44 percent and 0.26 percent per year between 1975 and 2007 (Table 5). In the Near East and North Africa as well as in East and Southeast Asia, population growth has eroded but not completely outweighed growth in the ACS. In Latin America and the Caribbean, the population active in agriculture has fallen at an average rate of almost 0.1 percent per year since 1975, contributing slightly to an overall increase in the ACS per worker in agriculture over this period.

**Table 5: Average annual rates of growth in ACS per worker in agriculture by developing country region (1975-2007, in percent)**

| Region | 1975-2007 annual rate of growth of... | | |
|---|---|---|---|
| | ...capital stock in agriculture | ...population active in agriculture | ...capital stock per person active in agriculture |
| Latin America & Caribbean | 1.24% | -0.08% | 1.33% |
| Near East & North Africa | 1.34% | 0.83% | 0.51% |
| Sub-Saharan Africa | 1.52% | 1.97% | -0.44% |
| East & Southeast Asia | 1.70% | 0.97% | 0.72% |
| South Asia | 1.11% | 1.38% | -0.26% |

Figure 3 presents information on gross and net investments in the ACS for the developing and the developed countries. Net investment is calculated as the simple difference between the ACS in year *t+1* and year *t*. Gross investment is calculated assuming that in addition to net investment, 5 percent of the ACS in year *t* depreciated and was replaced.

### 3.2. Components of the agricultural capital stock

Of the four categories of agricultural capital in the FAOSTAT physical inventories estimates, land is clearly the most important, with a value share that is consistently between 52 and 55 percent of the total agricultural capital stock (Figure 4). Livestock is next with a share of 24 to 26 percent, followed by machinery (16 to 17 percent) and structures (5 percent).

**Figure 3: Gross and net investments in the agricultural capital stock – developing and developed countries (1976-2007, in billion 1995 US$)**

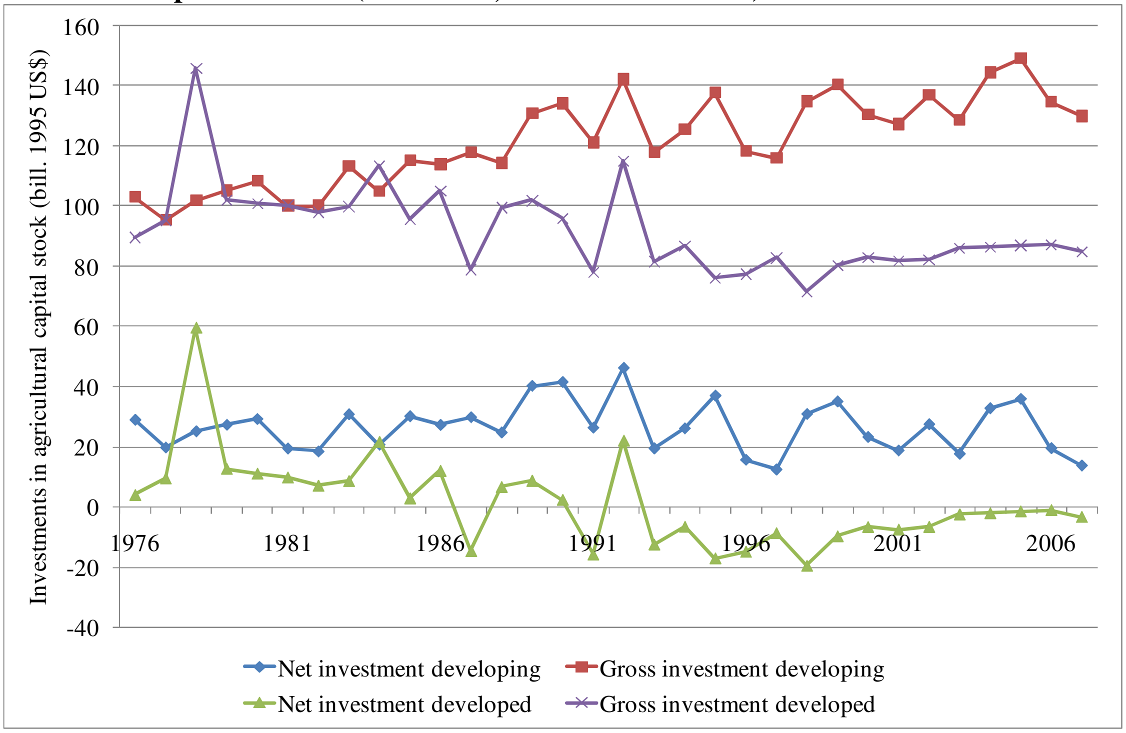
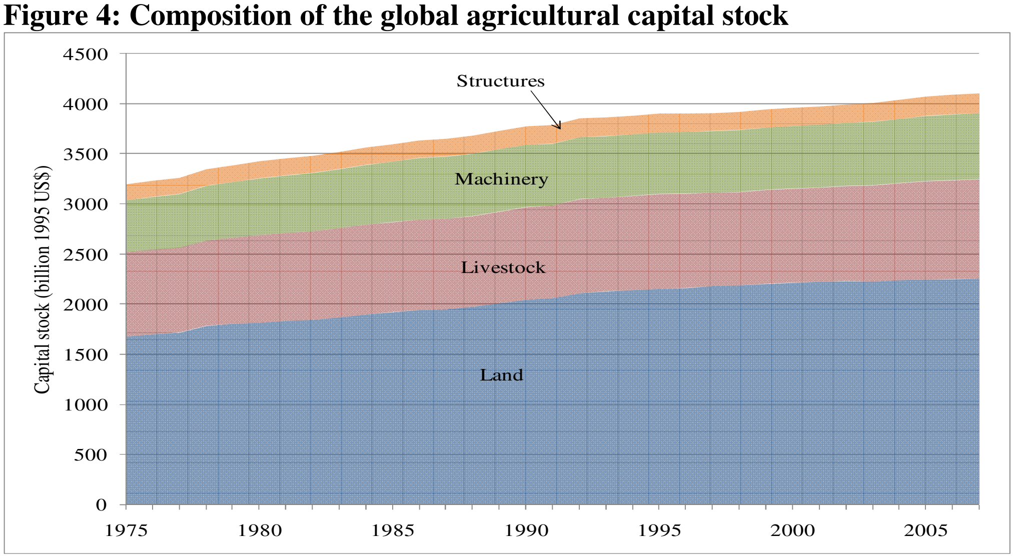
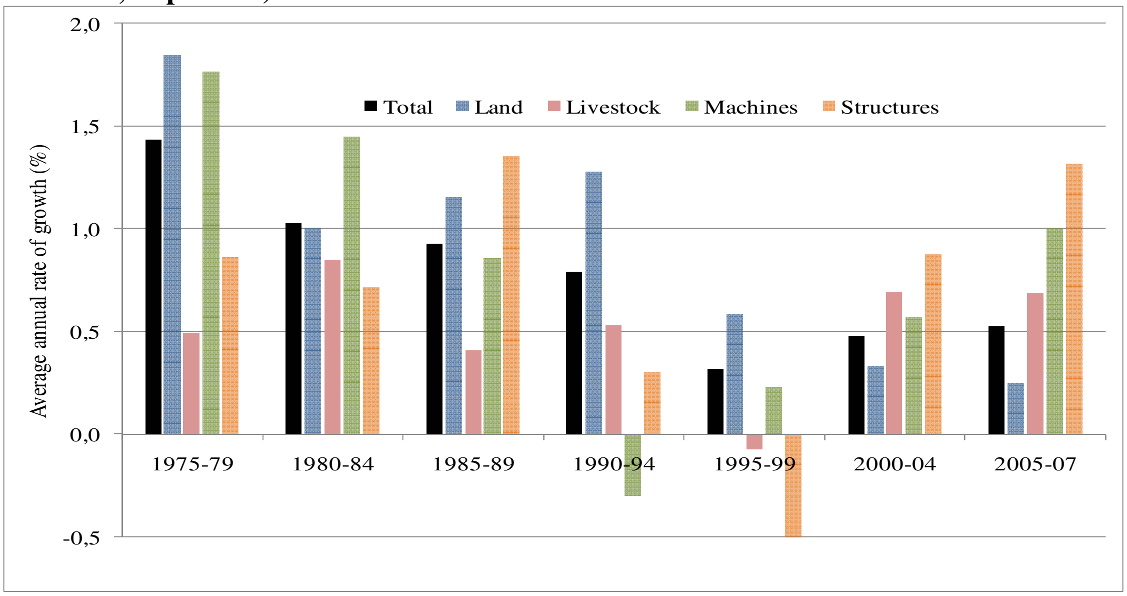



**Figure 4: Composition of the global agricultural capital stock**




All four components of the ACS increased between 1975 and 2007. Expressed in average annual rates of growth, the land component of the ACS increased by 0.93 percent per annum over this period, while livestock increased by 0.50 percent, machinery by 0.75 percent, and structures by 0.66 percent. However, the individual components evolved differently over time. The rates of growth in the livestock, machinery and structures components of the ACS fell in the course of the 1980s, reaching low, negative rates in the first (machinery) or second (livestock, structures) half of the 1990s (Figure 5). Since 2000, the livestock, machinery and structures components of the ACS have once again displayed positive rates of growth. Land however has followed a different pattern. Average annual rates of growth in the land stock were never negative between 1975 and 2007 (Figure 5). However, they steadily declined over the entire period and have not recovered since 2000. Since the land component of the ACS measures the value of land improvements (investments in permanent crops, irrigation and arable land) this sustained slowdown in land growth is not necessarily due to increased scarcity of agricultural land alone. Instead, it can also reflect in part a reduction in the willingness to invest in improving the productivity of land.

**Figure 5: Average annual rates of growth in global ACS components (five-year periods since 1975, in percent)**




### 3.3. The agricultural capital stock and the prevalence and depth of hunger

The fact that population growth has outstripped ACS growth ACS in sub-Saharan Africa and South Asia is worrying because many countries with severe hunger problems are located in one of these two regions. To cast more light on this issue, we explore the relationship between ACS growth and the prevalence and depth of hunger as defined by the FAO (2008). Hunger prevalence is defined according to the proportion of the population that is undernourished, and the depth of hunger is defined according to the gap between actual caloric consumption by the undernourished and minimum dietary energy requirements (MDER).

The estimates in Table 6 and Table 7 indicate that the ACS per person active in agriculture has indeed grown least in those countries with the highest prevalence and depth of hunger. In the countries in hunger prevalence categories 4 and 5 (>20 percent undernourished), growth in the ACS has been outstripped by population growth, resulting in a reduction in the level of ACS per person active in agriculture. The same is true for those countries in depth of hunger category 4 (where the average undernourished individual consumes less than 88 percent of his/her MDER). In both tables, China is listed separately because it would otherwise obscure the other countries in its respective hunger prevalence and depth of hunger categories.

**Table 6: Average annual rates of growth in ACS per worker in agriculture by hunger prevalence category* (1975-2007, in percent)**

| Hunger prevalence category (only developing countries) | 1975-2007 annual rate of growth of... | | |
|---|---|---|---|
| | ...capital stock in agriculture | ...population active in agriculture | ...capital stock per person active in agriculture |
| 1 (<5% undernourished) | 1.21% | 0.27% | 0.93% |
| 2 (5-9% undernourished) | 1.88% | -0.11% | 2.00% |
| 3 (10-19% undernourished) | 1.83% | 1.55% | 0.28% |
| 4 (20-35% undernourished) | 1.22% | 1.48% | -0.25% |
| 5 (>35% undernourished) | 1.29% | 2.16% | -0.85% |
| China (9% undernourished) | 1.71% | 0.96% | 0.74% |

** Note: Hunger prevalence categories based on 2003-2005 data from FAO (2008).*

**Table 7: Average annual rates of growth in ACS per worker in agriculture by depth of hunger category* (1975-2007, in percent)**

| Depth of hunger category (only developing countries) | 1975-2007 annual rate of growth of... | | |
|---|---|---|---|
| | ...capital stock in agriculture | ...population active in agriculture | ...capital stock per person active in agriculture |
| 1 (gap <7% of MDER) | 0.73% | -1.98% | 2.76% |
| 2 (gap 7-9% of MDER) | 1.53% | 0.83% | 0.69% |
| 3 (gap 10-12% of MDER) | 1.53% | 0.94% | 0.59% |
| 4 (gap >12% of MDER) | 1.47% | 1.77% | -0.30% |
| China (gap 12.6%) | 1.71% | 0.96% | 0.74% |

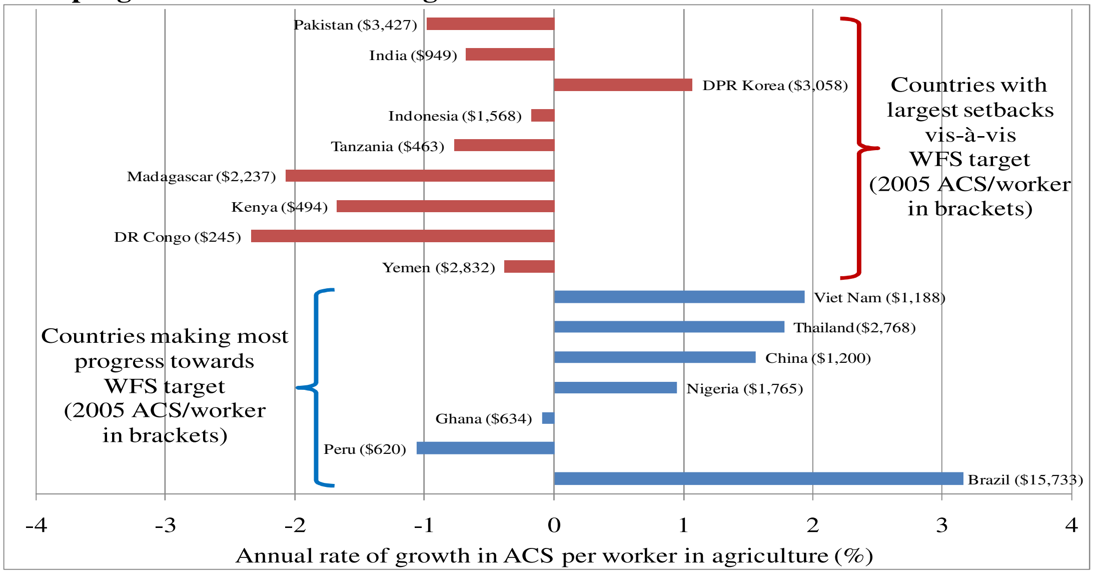
** Note: Depth of hunger categories based on 2003-2005 data from FAO (2008).*

### 3.4. The agricultural capital stock in countries with success in hunger reduction

If it is true that countries with high prevalence and depth of hunger are characterised by lower levels of investment in ACS, is there also evidence that countries that have been successful in reducing hunger are characterised by higher rates? Figure 6 presents information on annual rates of ACS growth between 1990 and 2005 for developing countries that the FAO (2008, p. 16) identifies as having made the most progress or as having experienced the largest setbacks with respect to the 1996 World Food Summit (WFS) target of halving the number of hungry by 2015. With the exception of the Democratic People's Republic of Korea, all of the developing countries that have suffered notable setbacks had negative rates of ACS growth between 1990 and 2005, and with the exception of Peru (and slight exception of Ghana), all countries that made notable progress had positive rates of ACS growth.

The relatively high rate of ACS growth recorded for the DPR Korea must be interpreted with caution because it is difficult to confirm official statistics in this country; Peru's progress toward the WFS target despite a negative rate of ACS growth may be due the resolution of internal conflicts and unrest in the course of the 1990s. Note that according to the national accounts-based ACS estimates, Peru is actually one of the better performing countries, with positive accumulation of ACS per worker for the same period. Ghana has made good progress towards the WFS target and is on track for MDG1, but has witnessed slightly negative ACS growth. This suggests that the determinants of success have been outside the farm sector itself. In fact, a recent OECD study (Dewbre and Debattisti, no date) concludes that Ghana's success in poverty reduction may have been caused less by on-farm investments than by public investments in research, technology and infrastructure leading to strong growth and income diversification in the rural non-farm economy.

**Figure 6: Annual rates of ACS growth (1990-2005) in countries that have made the most progress or suffered the largest setback towards the 1996 World Food Summit targets**



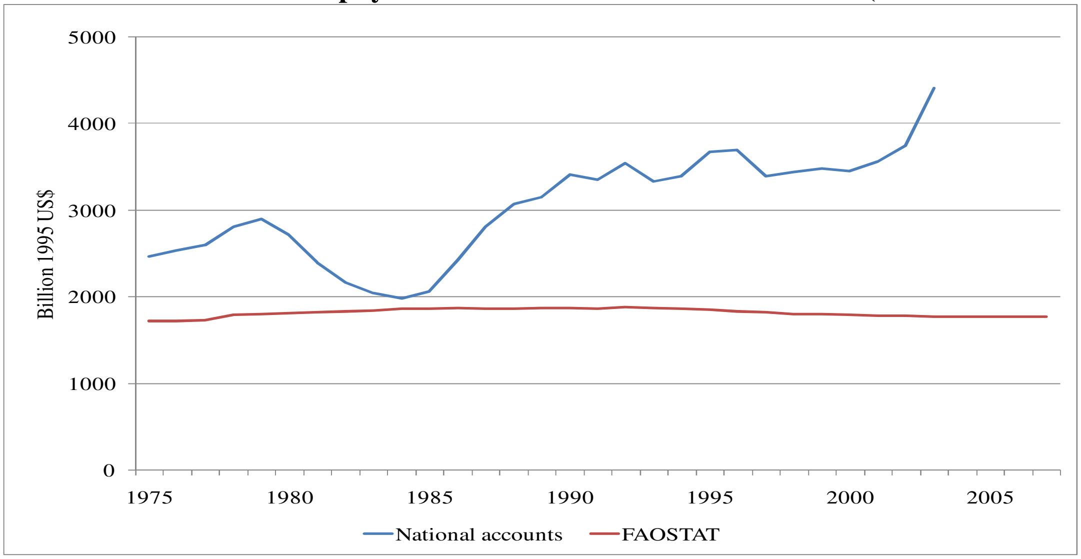

### 3.5. Comparing the national account and FAOSTAT approaches

The results discussed so far have been drawn from the FAOSTAT physical inventories estimates of the ACS. Since these estimates cover essentially all countries, they lend themselves to the calculation of the regional and global aggregates presented above. However, these estimates do suffer from methodological weaknesses. A comparison with estimates of the ACS based on the national accounts methods can cast some light on the robustness of the FAOSTAT estimates and the advantages and disadvantages of the two approaches.

Both the national accounts and the FAOSTAT estimates cover almost the same set of developed countries (30 in the case of the national accounts estimates, 31 in the FAOSTAT estimates – see Table 2). Hence, an almost direct comparison of levels and changes is possible for these countries. Although the focus of this paper is developing countries, we therefore begin by comparing the national accounts and FAOSTAT estimates for developing countries. This comparison reveals important discrepancies (Figure 7). First, the national accounts method produces a higher overall estimate of the ACS. This is presumably due to its more comprehensive coverage of the ACS; the gross capital formation data on which the national accounts estimates are based will capture investments that are not included in the limited set of assets that are covered by FAOSTAT.

Second, the national accounts estimates are more volatile than the FAOSTAT estimates. This reflects a fundamental difference between the estimates. The FAOSTAT estimates are calculated using a constant set of 1995 prices. The use of changing prices, deflators and exchange rates in the calculation of the national accounts-based estimates means that they capture not only changes in the volume of the ACS, but also changes in its valuation. For example, the drop in the national accounts-based ACS estimates in developed countries displayed in the first half of the 1980s (Figure 7) is presumably due to the strength of the US-dollar over this period, which reduced the US-dollar value of the ACS in other developed countries for example in Europe. Examination of the national accounts-based dataset for other regions (not shown) reveals that this drop was even more marked in Latin America, where currencies depreciated heavily against the dollar as a consequence of the debt crisis in the early 1980s; similar evidence of a fall in ACS is also revealed for Asia and to a lesser extent Africa at this time. We do not have up-to-date numbers on the evolution of the ACS in 2008-09, but the experience of past global debt crises suggests that they can provoke large and protracted dents in the evolution of agricultural capital.

**Figure 7: Total agricultural capital stock in developed countries – comparing national accounts and FAO physical inventories estimates since 1975 (billion 1995 US$)**




Finally, the national accounts estimate for developed countries trends strongly upward over the entire period since 1975, while the FAOSTAT estimate show only a very slight increase overall, and a sustained downward trend in the 1990s. This difference is at least partly due to the use of constant prices in the FAOSTAT approach, as a result of which the FAOSTAT estimates fail to capture increases in the quality of many components of the ACS over time. However, Table 8 shows that the national accounts estimates do not trend upwards for all regions. Seven of the nine sub-Saharan African countries in the national accounts database, and all three of the South Asian countries, display negative ACS trends between 1975 and 2003, while eight of the same nine and three of three, respectively, display positive ACS trends in the FAOSTAT database. It appears that the two approaches to estimating the ACS are producing substantially different results.

**Table 8: Trends in the development of the agricultural capital stock by region – a comparison of the national accounts and FAOSTAT physical inventories estimates (1975-2003)**

| Region (number of countries) | National accounts estimates | | | FAOSTAT estimates | | |
|---|---|---|---|---|---|---|
| | Positive trend | Negative trend | No sig. trend | Positive trend | Negative trend | No sig. trend |
| North America (2) | 0 | 2 | 0 | 1 | 1 | 0 |
| Western Europe (16) | 3 | 8 | 5 | 5 | 8 | 3 |
| Oceania (2) | 2 | 0 | 0 | 0 | 0 | 2 |
| Other developed (3) | 1 | 0 | 2 | 2 | 0 | 1 |
| Transition Economies (10) | 4 | 4 | 2 | 4 | 0 | 6 |
| Latin America & Caribbean (17) | 3 | 9 | 5 | 13 | 2 | 2 |
| Near East & North Africa (9) | 6 | 2 | 1 | 9 | 0 | 0 |
| Sub-Saharan Africa (9) | 0 | 7 | 2 | 8 | 0 | 1 |
| East & Southeast Asia (4) | 4 | 0 | 0 | 4 | 0 | 0 |
| South Asia (3) | 0 | 3 | 0 | 3 | 0 | 0 |
| Other Developing (1) | 1 | 0 | 0 | 1 | 0 | 0 |
| Total (76) | 39 | 24 | 13 | 50 | 11 | 15 |

The comparison in Table 8 is based on the 76 countries in the national accounts database. Comparison for the many especially developing countries that are not included in this database is clearly not possible. Given the theoretical advantages of the national accounts approach to measuring the ACS, we could base our entire discussion on results produced using this method, if we could be sure that these results are based on a representative sample of countries. However, this does not appear to be the case. Table 9 presents estimates of the ACS per person employed in agriculture for groups of developing countries in different hunger prevalence categories. One set of estimates is based on the national accounts approach, and two are based on the FAOSTAT approach using first the full sample of countries, and second only the countries in the national accounts database. The estimates based on the national accounts approach are uniformly higher than those based on the FAOSTAT physical inventories approach, a result which mirrors that found for the aggregate of developed countries (see Figure 7). Furthermore, the result that the ACS per person employed in agriculture is declining in the countries with the highest prevalence of hunger (see Table 6) is confirmed with the national accounts-based estimates.

However, the national accounts based estimates are based on fewer developing countries than the FAOSTAT results. For example there are 9 countries in hunger prevalence category 4 in the national accounts database, compared with 24 in the FAOSTAT database (Table 9). If the FAOSTAT results are recalculated for only those countries that are included in the national accounts database, evidence of selection bias becomes apparent. Specifically, with the exception of hunger prevalence category 2 in the 1970s and 1980s, the FAOSTAT estimates increase, often considerably, if only the restricted sample of countries in the national accounts database is considered. In hunger prevalence category 4, for example, the estimate of the ACS per worker in agriculture is 1,353 US$ in the full FAOSTAT sample of 24 countries, but increases to 3,888 US$ if only the 9 hunger prevalence category 2 countries included in the national accounts data are considered.

A comparison of the lists of countries in hunger prevalence category 4 included in the two databases confirms that selection bias may be playing a role. In addition to the 9 countries in the national accounts database, the FAOSTAT database includes a number of countries (e.g., Bangladesh, Cambodia, Cameroon, Democratic Republic of Congo and Senegal) that have considerably lower levels of ACS per worker in agriculture (Table 10). One might conjecture that a developing country's level of ACS per worker in agriculture is correlated with its ability to provide the detailed national accounts information required for the calculation of national accounts based ACS estimates. If this is true, the national accounts method will tend to overestimate ACS levels at the aggregate level in groups of developing countries.

**Table 9: The agricultural capital stock per individual active in agriculture by hunger prevalence category – different approaches and samples of countries (US$/capita)**

| Hunger prevalence category | 1975-79 | 1980-84 | 1985-90 | 1991-94 | 1995-99 | 2000-03 | *# of countries in sample* |
|---|---|---|---|---|---|---|---|
| **National accounts approach** | | | | | | | |
| 2 | 10404 | 8445 | 9053 | 12719 | 15671 | 15404 | *3* |
| 3 | 16128 | 12897 | 9341 | 8857 | 9492 | 9660 | *11* |
| 4 | 6833 | 5139 | 3780 | 3476 | 3848 | 3796 | *9* |
| 5 | 3027 | 2086 | 1613 | 1368 | 1026 | 940 | *3* |
| **FAOSTAT physical inventories approach (full sample)** | | | | | | | |
| 2 | 3660 | 4122 | 4535 | 5104 | 5315 | 5820 | *20* |
| 3 | 1636 | 1668 | 1675 | 1906 | 2070 | 2076 | *28* |
| 4 | 1391 | 1389 | 1371 | 1398 | 1397 | 1353 | *24* |
| 5 | 891 | 880 | 854 | 820 | 773 | 724 | *18* |
| **FAOSTAT physical inventories approach (same sample as national accounts approach)** | | | | | | | |
| 2 | 3524 | 3860 | 4430 | 5283 | 5863 | 6569 | *3* |
| 3 | 4192 | 4409 | 4343 | 5084 | 5644 | 5862 | *11* |
| 4 | 2338 | 2322 | 2246 | 3001 | 3692 | 3888 | *9* |
| 5 | 1470 | 1493 | 1480 | 1434 | 1355 | 1266 | *3* |

**Table 10: Comparison of countries in hunger prevalence category four in the national accounts and FAOSTAT physical inventories databases**

| Countries in both databases | Countries only in the FAOSTAT database | |
|---|---|---|
| 1. Bolivia | 10. Grenada | 19. Sudan |
| 2. Botswana | 11. Nicaragua | 20. Cambodia |
| 3. Dominican Republic | 12. Yemen | 21. Timor-Leste |
| 4. India | 13. Cameroon | 22. DPR Korea |
| 5. Kenya | 14. DR Congo | 23. Mongolia |
| 6. Malawi | 15. Djibouti | 24. Bangladesh |
| 7. Niger | 16. Gambia | |
| 8. Pakistan | 17. Guinea-Bissau | |
| 9. Sri Lanka | 18. Senegal | |

Altogether, the results of the various comparisons presented in this section are sobering. They reveal important differences between the two sets of estimates. While both approaches point to a reduction in the ACS per person employed in agriculture in countries with the greatest prevalence of hunger, in other respects (e.g. the development of the ACS in developed countries) there are large discrepancies. The inescapable conclusion is that we know too little about the ACS, despite its obvious great importance for efforts to combat hunger.

Each of the approaches to estimating the ACS suffers from important weaknesses which limit its usefulness as a basis for deriving robust conclusions and policy implications. The FAOSTAT-based estimates only cover certain components of the ACS. The national accounts-based estimates only cover a (probably non-representative) sample of developing countries. However, each approach also has important advantages. The FAOSTAT approach provides global coverage over a long period. If the assets that it includes are representative of the overall ACS, it provides a robust basis for comparisons across countries/regions and time. The national accounts estimates provide additional information on the value, as opposed to only the volume, of the ACS.

For the moment, all that can be done is to work carefully with both sets of estimates and to interpret them carefully. For the future, priority must be given to improving these estimates and resolving the differences between them. A first step would be to update the constant 1995 prices used to generate the FAOSTAT estimates, for example to 2000 and 2005. Efforts should also be made to expand the set of countries included in the national accounts database, with a special emphasis on developing countries that are characterised by high prevalence and depth of hunger. Producing robust estimates of the ACS that combine the coverage of the FAOSTAT approach with the greater conceptual consistency of the national accounts approach will require a significant commitment of resources, but the effort must be made.

### 3.6. The agricultural capital stock and public expenditure on agriculture

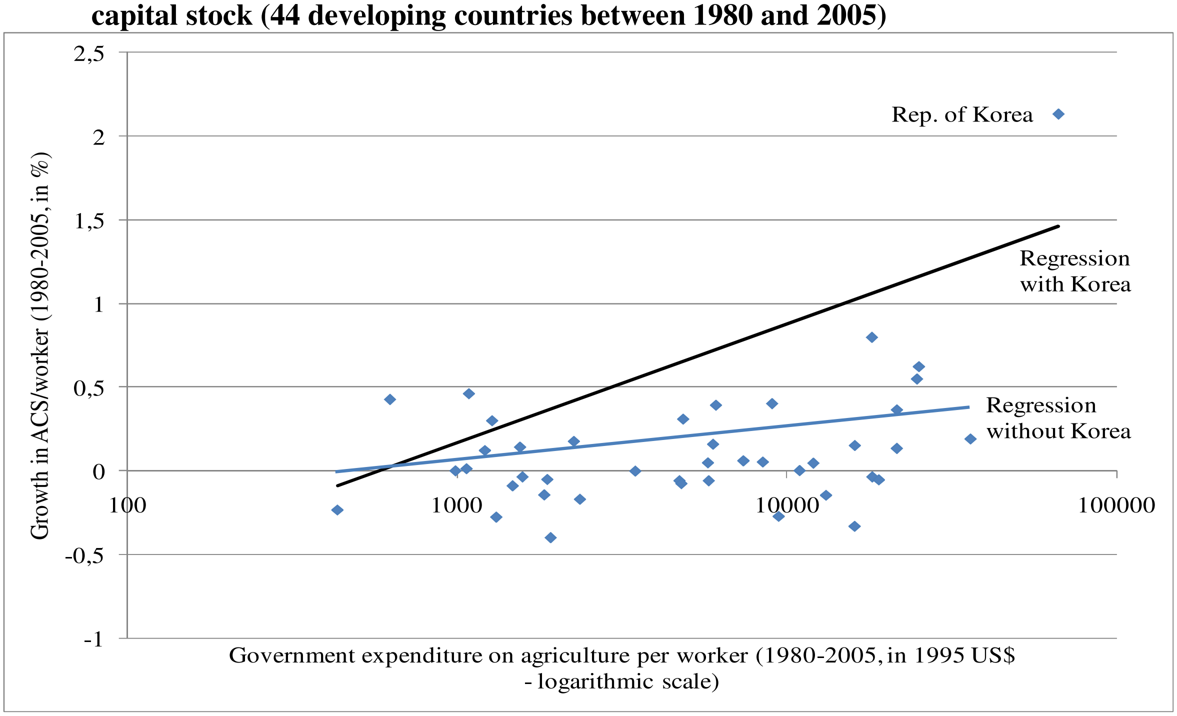
To what extent does public expenditure in agriculture supports investment in the ACS? Two types of public expenditure are relevant in this regard; national government expenditure and international expenditure in the form of official development assistance (ODA). Although we discuss these types of public expenditure separately in the following, we are aware that available statistics do not always clearly distinguish between them so that double counting may occur. We also note that not all public expenditure which supports the production capacity of the food and agricultural sectors or more generally benefits the rural population is included in official agricultural budgets.

*a) National public spending*. Several studies have shown that the level of public national spending on agriculture and rural areas has fallen during the 1990s and early 2000s. In its 2001 report, FAO noted "...that in countries with a very high incidence of undernourishment, public expenditure on agriculture does not reflect the importance of the sector in overall income or its potential contribution to the alleviation of undernourishment" (FAO 2001b). While some of the earlier decline was the result of structural adjustment programmes and has even led to a more efficient resource allocation, the main effect of low public expenditure was an inadequate provision of public services and lacking infrastructure and hence missing incentives for investment by the farms and other private investors in rural areas.

Country panel data on national government expenditure and ODA which matches the ACS data presented here over time and in cross section is not available. Fan and Rao (2003) describe the compilation of a panel on national government expenditure for a set of 43 developing countries from across Asia, Africa, and Latin America from 1980 to 1998. This dataset has since been expanded to 44 countries and updated to 2005.[4] It points to increasing real levels of government expenditure for the aggregate of all 44 countries over time. Figure 8 provides evidence of a robust positive relationship between government expenditure on agriculture and growth in the ACS in these countries over the period 1980 to 2005.

*b) International assistance*. As has been documented elsewhere, external assistance to agriculture in developing countries has declined since the late 1980s. At the country level, the relationship between agricultural ODA and the ACS growth (Figure 9) is not as clear-cut as in the case of government agricultural expenditure and ACS growth. The correlation coefficient between agricultural ODA receipts between 1995 and 2005 and growth in the ACS over the same period for 118 developing countries in the ODA database equals 0.48. However, the relation is weakened by the fact that several countries (e.g. Brazil, Sudan, Myanmar, Turkey and Syria) have recorded large increases in their ACS despite receiving comparatively low amounts of agricultural ODA (Figure 9). Of course, it is not surprising that a country such as Brazil does not depend on agricultural ODA. Furthermore, if a few countries that have received large amounts of ODA are omitted (e.g. India, Vietnam, Indonesia, Pakistan, Bangladesh and Thailand) there appears to be no significant relationship between agricultural ODA receipts and growth in the national ACS for the remaining countries.

**Figure 8: Government expenditure on agriculture per worker and growth in the agricultural capital stock (44 developing countries between 1980 and 2005)**




** Data on government expenditure on agriculture kindly provided by Shenggen Fan (see Fan and Rao, 2003).*

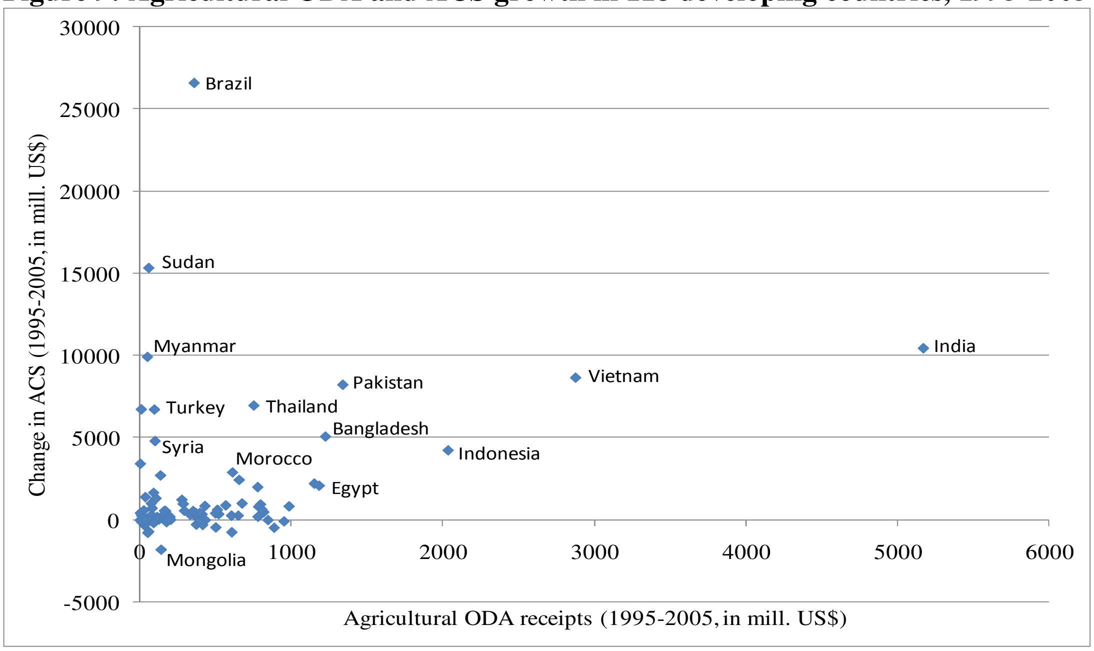
Besides direct public investment, favourable market prospects and other components of the overall investment climate such as stability and security, regulation and taxation, finance and infrastructure and a functioning labour market play a decisive role in determining the rate of ACS growth. In its World Development Report 2005, the World Bank (2005b, p. xiii) observed that "more governments are recognizing that their policies and behaviours play a critical role in shaping the investment climate of their societies and they are making changes". However, the Report also underlines the need for much more progress, especially in rural areas.

[4] We are grateful to Shenggen Fan for making this data available to us.

## 4. THE AGRICULTURAL CAPITAL STOCK AND PRODUCTIVITY

The updated estimates of the ACS presented above provide a basis for generating estimates of changes in total factor productivity (TFP) in individual countries and regions. TFP analysis can cast light on the extent to which countries have succeeded in translating investment in agriculture into productivity gains. To this end, we take as a starting point a study in which Rao et al. (2004) estimate TFP changes in agriculture using panel data on agricultural inputs and output in 111 countries between 1970 and 2001.5 The main aim of our analysis is to determine whether TFP estimates change when our updated and expanded estimates of the ACS are used. Rao et al. (2004) used land, tractors and an aggregate of five types of livestock as capital inputs; besides land we are able to consider four types of machinery, nine types of livestock and structures using our FAOSTAT physical inventories data.

**Figure 9: Agricultural ODA and ACS growth in 118 developing countries, 1995-2005**




### 4.1. Methods

Rao et al. (2004) employ data envelopment analysis (DEA) to estimate the technical efficiency of agriculture for each country in their dataset, and to derive shadow prices for agricultural inputs and outputs. They then use the Malmquist productivity index to measure growth in TFP and to decompose TFP growth into its two main components: technical change (i.e. shifts in the production frontier over time) and efficiency change (i.e. a production unit's ability to move closer to the production frontier). Both methods are well-established in the literature, so no review is provided here (see for example Coelli et al., 2005). The application of these methods to panel data of countries over time treats each country in its entirety as an individual production unit and assumes that all countries have access to the same technology that underlies the frontier.

We apply these methods using the FEAR package in the programming language R (Wilson, 2008). We present a series of estimates beginning with those reported in Rao et al. (2004), which we replicate to confirm that there are no computational discrepancies (Model I). These are followed by a series of estimates in which different aspects of the data, model and/or estimation technique are modified to produce alternative results. Modifications account for the following factors:

a) Rao et al.'s (2004) data contains a minor mis-coding of data which leads livestock output to be listed as crop output and *vice versa* for North and Central America. This is rectified in Model II.

[5] We are grateful to Prasada Rao and Tim Coelli for making their data available to us.

b) Zelenyuk (2006) introduces a weighted TFP estimation technique that produces consistently aggregated regional averages. He demonstrates that this technique is superior to the standard approach of calculating output-weighted aggregates of individual country TFP estimates. Model III employs Zelenyuk's (2006) method.

c) The updated FAOSTAT ACS data presented earlier in this paper begin in 1975 and extend to 2007, while Rao et al. (2004) use data from 1970 to 2001. To make subsequent comparisons possible, we first present average TFP growth rates for the 1970-2001 period that account for both the output data mis-coding and aggregation method changes mentioned above (Model IVa = Model II + Model III). We then present the results of this model for only 1975-2001 (Model IVb).

d) Maintaining the same 2-output, 5-input model estimated by Rao et al. (2004), we replace their land, tractor and livestock input data with the more comprehensive land, machinery and livestock estimates in our FAOSTAT ACS data for the period 1975-2001 (Model V).

e) In DEA estimation, the so-called 'curse of dimensionality' can influence results (Daraio and Simar, 2007). Essentially, as more inputs and outputs are included in the estimation procedure, the best-practice frontier becomes increasingly flexible in higher-dimension space. This permits it to accommodate individual observations better, creating the impression that they are all close to the frontier and distorting subsequent TFP estimates. To reduce this problem, we re-estimate Model V but with the data aggregated to 1 output and 4 inputs (as opposed to 2 and 5). The reduced 1-by-4 dimension is chosen based on recommendations provided by Park et al. (2000) and Daraio and Simar (2007, pp. 153-154). We present results for 1975-2001 (Model VIa) and then for 1975-2007 (Model VIb) to take advantage of the longer time period covered by our FAOSTAT ACS data.

f) As an alternative means of dealing with dimensionality, partial or so-called robust frontiers can be estimated based on the m-order expected maximum output frontier proposed by Cazals et al. (2002). The basic idea of this method is to estimate a more 'taut' frontier which does not envelop all the data points by repeated, local re-sampling from the set of available observations. The advantages of the m-order method are summarized by Daraio and Simar (2007); they include robustness to outliers in the data, and less susceptibility to the curse of dimensionality. We employ this method in Model VII which uses 2 outputs and all 6 available inputs (land and labour as in Rao et al. (2004), and the 4 capital inputs in our FAOSTAT ACS data).

In all estimations, labour, land and fertiliser (as a proxy for working capital) are included as inputs, along with the various measures and aggregations of capital input as outlined above.

**Table 11: TFP growth in different regions of the world according to different specifications and estimation techniques (average annual rate of TFP growth in percent)**

| Model | Time period* | Specification (outputs = n, inputs = m) | North Africa & the Middl e East | Sub-Sahar a Africa | North Am. & Pacific | Latin Am. | Asia w/o Chin a | Chin a | Europ e | Trans -ition | Worl d |
|---|---|---|---|---|---|---|---|---|---|---|---|
| I = Rao et al. (2004), 2 outputs (crop & livestock) & 5 inputs (labour, fertiliser, land, tractors & livestock) | 1970-01 | DEA n = 2, m = 5 | 0.6 | 0.3 | 2.2 | 0.7 | 0.3 | 3.0 | 1.9 | 1.4 | 1.5 |
| II = I + corrected output data† | 1970-01 | DEA n = 2, m = 5 | 0.8 | 1.5 | 2.3 | 0.7 | 0.5 | 2.8 | 2.1 | 1.9 | 1.4 |
| III = I + corrected aggregation‡ | 1970-01 | DEA n = 2, m = 5 | 0.7 | 0.6 | 1.9 | 0.9 | 0.2 | 2.5 | 1.9 | 2.2 | 1.2 |
| IVa = II + III | 1970-01 | DEA n = 2, m = 5 | 0.6 | 0.4 | 2.3 | 0.4 | 0.2 | 2.5 | 2.1 | 1.9 | 1.4 |
| IVb = IVa beginning in 1975 | 1975-01 | DEA n = 2, m = 5 | 0.8 | 1.2 | 2.5 | 0.3 | 0.4 | 4.6 | 2.3 | 2.4 | 1.8 |
| V = IVb + new FAOSTAT estimates for land, machinery (in lieu of tractors) & livestock inputs | 1975-01 | DEA n = 2, m = 5 | 1.6 | 1.5 | 2.5 | 1.2 | 0.8 | 2.7 | 1.9 | 2.1 | 1.6 |
| VIa = V with 1 aggregate output° & 4 inputs (labour, fertiliser, land & capital = structures, machinery & livestock) | 1975-01 | DEA n = 1, m = 4 | 0.9 | 1.6 | 2.3 | 0.2 | 1.3 | 2.2 | 1.8 | 1.8 | 1.5 |
| VIb = VIa extended to 2007 | 1975-07 | DEA n = 1, m = 4 | 0.9 | 1.8 | 2.2 | 0.6 | 1.5 | 2.1 | 1.5 | 1.8 | 1.5 |
| VII = VI with 2 outputs (crop & livestock) & 6 inputs (labour, fertiliser, land, structures, machinery & livestock) | 1975-07 | m-order n = 2, m = 6 | 1.5 | 0.9 | 2.0 | 1.0 | 1.4 | 2.1 | 1.4 | 1.7 | 1.7 |

* All results exclude 1992 and 1993 as these produce highly variable estimates due to the impact of the breakup of the Soviet Union, the Yugoslav SFR and Czechoslovakia on input and output statistics.

† In the original Rao et al. (2004) data set (kindly made available by the authors), crop output values are listed as livestock output values and *vice versa* for North America and Central American countries. This is corrected here.

‡ Zelenyuk (2006) introduces a weighted TFP estimation technique that produces consistently aggregated regional averages. He demonstrates that this technique superior to the standard approach of calculating output-weighted aggregates of individual country TFP estimates.

° Output series are aggregated using 1999-2001 average international prices.

### 4.2. Results

A comparison of the different estimates of TFP change by region of the world reveals a number of results that are robust to the data, model and estimation technique alternatives outlined above (Table 11). At the global level, estimates of annual TFP growth are quite consistent across models, ranging from 1.2 to 1.8 percent per year. Comparing Models IVa and IVb reveals that omitting the first half of the 1970 leads to increased estimates of TFP growth in all regions except Latin America. The increase is especially large for China. This suggests that the first years of the 1970s were characterised by below average TFP growth in most of the world. Comparing Models VIa and VIb reveals that increasing the coverage to include 2002-2007 has no major impact on results.

North America and Oceania, Europe, the Transition countries and China exhibit above-average rates of TFP growth that are relatively robust to the estimation method used. North Africa and the Middle East, sub-Saharan Africa, Latin America and Asia (without China) exhibit below-average levels that are less robust, with estimates for sub-Saharan Africa, for example, ranging from 0.3 to 1.8 percent, and estimates for Asia (without China) ranging from 0.2 to 1.5 percent. This probably reflects the fact that the quality of the underlying data for the countries in these regions is comparatively low; DEA estimation is known to be highly sensitive to aggregation and data quality (Fuglie, 2008, p. 433; Daraio and Simar, 2007). This might also explain why, when Models I and II are compared, correcting the mis-coded North and Central American output data has little impact on TFP growth rates for most regions, but a large impact on sub-Saharan Africa, where estimated TFP growth rates increase from 0.3 to 1.5 percent.

With this evidence of sensitivity in mind, the m-order estimates presented in Table 11 might be considered the most reliable, as the m-order method is much less sensitive to outliers. For this reason, the decomposition of TFP growth rates into efficiency change and technical change components in Table 12 is based on the m-order estimates. The results of this decomposition reveal that in North Africa and the Middle East, China and the Transition countries efficiency improvements have made relatively large contributions to TFP growth. In all other regions, TFP change has been largely determined by technical change. High rates of efficiency improvement in the Transition countries and China are expected as the restrictions and inefficiencies of central planning have been removed over the study period.

**Table 12: Estimated changes in TFP and its components by region (1975-2007, in percent)**

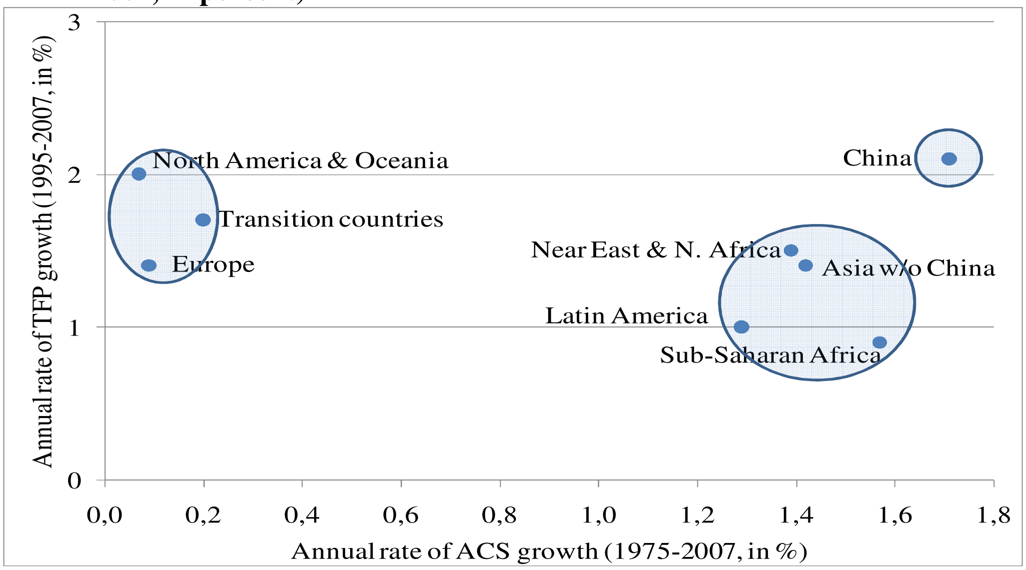
| Time period | Efficiency change | Technical change | TFP change |
|---|---|---|---|
| North Africa & Middle East | 1.4 | 0.1 | 1.5 |
| Sub-Saharan Africa | 0.3 | 0.6 | 0.9 |
| North America and Pacific | -0.7 | 2.7 | 2.0 |
| Latin America | 0.3 | 0.7 | 1.0 |
| Asia without China | -0.9 | 2.3 | 1.4 |
| China | 0.9 | 1.3 | 2.1 |
| Europe | 0.3 | 1.1 | 1.4 |
| Transition countries | 0.7 | 1.0 | 1.7 |
| *World* | *0.7* | *1.0* | *1.7* |

Note: Results based on m-order estimates in Table 11. Results exclude 1992 and 1993 as these produce highly variable estimates due to the impact of the breakup of the Soviet Union, the Yugoslav SFR and Czechoslovakia on input and output statistics.

Comparing TFP change and ACS accumulation over the period between 1975 and 2007 period reveals some interesting patterns. The industrialised countries (Europe, North America, Oceania and the Transition countries) are characterised by low rates of ACS growth and relatively high rates of TFP growth (Figure 10). Their TFP growth over the study period is largely due to technical change (except in the Transition countries where efficiency improvements have also played a role). This is presumably a reflection of increases in input quality that are not captured by the FAOSTAT ACS estimates; TFP estimates based on the national accounts estimates of capital inputs would likely point to lower rates of TFP growth. The developing countries are characterised by much higher rates of ACS growth but, in Latin America and especially sub-Saharan Africa, lower rates of TFP growth. China stands out as having both the highest rates of ACS and TFP growth. These results underline that high ACS growth does not necessarily lead to higher TFP growth.

All of the TFP estimates in Table 11 and Table 12 are based on non-parametric techniques and data on capital inputs that is derived from FAOSTAT. Ongoing work is looking into parametric estimation using stochastic frontier methods on the same data, and into both non-parametric and parametric estimates using national accounts-based capital input data. Of course, any use of the national accounts-based data will have to deal with the issue of selection bias identified above in section 3.5.

**Figure 10: Annual rates of agricultural capital stock growth and TFP growth by region (1975-2001, in percent)**




### 4.3. Factors that influence TFP growth

In a series of regressions, Rao et al. (2004) study factors which explain TFP levels across countries, such as land quality, irrigation, government expenditure, literacy rates and trade openness. They find that results are sensitive to the period that is studied and whether or not the transition economies are included in the analysis, the latter point probably being due to questionable data for these countries and the unique circumstances in which they find themselves. Two robust results are that both reducing illiteracy and reducing the incidence of malaria have positive impacts on TFP in agriculture. Furthermore, foreign direct investment (FDI) as a share of GDP is found to have a uniformly positive impact on agricultural TFP, confirming the expectation that FDI will be associated with improved technologies and know-how to implement them. A surprising result of the analysis presented by Rao et al. (2004) is that both gross domestic investment as a share of GDP, and government consumption as a share of GDP, have negative effects on agricultural TFP. Rao et al. (2004) suggest that the latter result may be due to urban biases in government expenditure, so that much government consumption may actually be discriminating against agriculture in many countries. We revisit the issue of government expenditure and TFP using the Fan and Rao (2003) data on government expenditure on agriculture in developing countries. While this data on government expenditure is only available for 44 countries, it has the advantage of measuring government expenditure specifically on agriculture. Hence, unlike the general government consumption data employed by Rao et al. (2004), it should be free of any urban bias.

The regression analysis is based on panel data for 37 of the 44 developing countries in the Fan and Rao (2003) database from 1980 to 2005. Missing data for some of the independent variables described below leads to complete omission of 7 countries in the Fan and Rao (2003) data, and omission of individual observations for some of the remaining 37 countries. The result is an unbalanced panel with a total of 761 observations. The dependent variable is the logarithm of TFP levels for country *i* in year *j* calculated using base period TFP levels (relative to the United States of America) extrapolated with the m-order TFP estimates (see Rao et al., 2004, p. 29 for details). We use two based periods to account for the entrance of the Transition countries into the TFP estimation.

Drawing on Rao et al. (2004) and theoretical considerations, the following series of possible covariates is identified (descriptive statistics in Table 13):

a) A dummy variable that equals 0 prior to 1994 and 1 thereafter is added to account for the fact that in 1994 the Transition countries enter the TFP estimation described above. Although there are no Transition countries among the 37 countries included in this regression analysis, these countries affect TFP levels for all countries when they enter the TFP estimation.

b) The rural population as a share of the total population is included as a measure of labour abundance in agriculture, where a high share might point to surplus labour with a very low marginal product (source: *World Development Indicators*).

c) The ratio of imports + exports to GDP is a measure of economic openness that can capture access to foreign technology as well as the overall policy climate in a country (source: *World Development Indicators*).

d) The share of irrigated land in total agricultural land is a proxy for land quality (source: *FAOSTAT*).

e) An indicator of institutional quality that combines the quality of bureaucracy, the rule of law and the lack of corruption is added to measure the quality of government. This variable is standardised to ease interpretation (source: PRS Group's *IRIS dataset* – www.prsgroup.com).

f) A political regime index defined as a country's degree of democracy less its degree of autocracy is included to capture governance. This index is also standardised (source: *POLITY IV Project* – http://www.systemicpeace.org/inscr/inscr.htm).

g) Net foreign direct investment (FDI) flows as a share of GDP are included to capture inflows of technology and know-how that might be expected to boost TFP (source: *World Development Indicators*).

h) Gross fixed capital formation as a share of GDP might capture technology that is embodied in fixed capital (source: *World Development Indicators*).

i) The logarithm of government expenditure on agriculture is included in the expectation that higher levels of this expenditure will be associated with improved availability of productivity enhancing infrastructure, research and education (source: Fan and Rao, 2003).

Several interaction terms involving the institutional quality and political regime indicators are included in the final specification. The final specification includes country fixed effects which are found to be jointly significant at the 1 percent level. The regression model is estimated using the *plm* package in R (Croissant and Millo, 2008) and results are presented in Table 13.

**Table 13: Results of panel regression analysis to explain differences in national TFP growth (dependent variable is *log*[TFP level] in country *i* and year *j*)**

| Covariate | Regression results | | Descriptive statistics | | | |
|---|---|---|---|---|---|---|
| | Coefficient | Standard error | Mean | Min. | Max. | Std. error |
| Dummy1994-2005 | -0.308*** | 0.023 | 0.47 | 0.00 | 1.00 | 0.50 |
| Rural population as % of total pop. | -0.031*** | 0.003 | 54.7 | 6.60 | 93.6 | 23.3 |
| Exports + imports as % of GDP | 0.002* | 0.001 | 55.2 | 1.53 | 228.9 | 30.2 |
| Share of irrigated land in total ag. land | 0.111 | 0.292 | 0.10 | 0.00 | 1.00 | 0.19 |
| Institutional quality index | -0.109*** | 0.031 | 0.00 | -2.61 | 2.31 | 1.00 |
| Political regime index | 0.032 | 0.040 | 0.00 | -1.55 | 1.30 | 1.00 |
| Institutional quality * Political regime | -0.020* | 0.011 | 0.16 | -2.26 | 2.87 | 0.94 |
| FDI inflows as % of GDP | -0.016*** | 0.006 | 1.58 | -2.76 | 12.2 | 1.83 |
| FDI * Institutional quality | 0.032*** | 0.006 | 0.53 | -6.91 | 20.9 | 2.06 |
| FDI * Political regime | 0.020*** | 0.005 | 0.49 | 10,3 | 14.1 | 2.31 |
| Fixed capital formation as % of GDP | -0.007*** | 0.002 | 20.3 | 3.53 | 43.6 | 6.23 |
| Fixed capital * Institutional quality | 0.003* | 0.002 | 2.23 | 58.8 | 86.4 | 21.8 |
| Fixed capital * Political regime | -0.004** | 0.002 | 0.21 | 52.2 | 47.3 | 20.8 |
| *log*[Government expenditure on ag.] | 0.034** | 0.014 | 1.01 | -2.20 | 3.77 | 1.09 |
| *Period* | *1981-2005* | | | | | |
| *Number of observations* | *761* | | | | | |
| *$R^2$* | *0.32* | | | | | |
| *Significance levels* | ** (10%), ** (5%), *** (1%)* | | | | | |

The overall fit of the regression ($R^2$ = 32 percent) is good for a panel estimate with annual country data. Most of the estimated coefficients are significant and have the expected signs. A 10 percent increase in the share of the rural population reduces agricultural TFP by 0.31 percent, all other things being equal, while a 10 percent increase in the share of trade in GDP increases agricultural TFP by 0.02 percent. The share of irrigated land has the expected positive impact on TFP, but this effect is not significant. Like Rao et al. (2004) we find a surprising negative relationship between institutional quality and TFP levels. The impact of the political regime index (increasing democracy) on agricultural TFP is positive but not significant, while the interaction between institutional quality and the political regime has a negative impact.

FDI alone has a significant negative impact of agricultural TFP, but the interactions between FDI and the institutional quality and political regime variables are significantly positive and larger in magnitude. Hence, the impact of a 10 percent increase in net FDI inflows as a share of GDP is a 0.16 percent reduction in TFP at mean values of the institutional value and political regime covariates. But for a country that is one standard deviation above the mean in terms of its institutional quality and political regime, this turns into a net 0.36 percent increase. This result suggests that the institutional and governance environment within which FDI take place is of crucial importance. An appropriate environment can ensure that the potential productivity enhancing impacts of FDI are realised, while under conditions of poor governance and institutional quality, FDI will be more short term and perhaps more focused on rent extraction rather than establishing capacities for adding value. Fixed capital formation has a weak negative impact on agricultural TFP which is only partially compensated by the interaction between fixed capital formation and institutional quality, and somewhat strengthened by its interaction with the political regime variable. The overall negative effect of capital formation on agricultural TFP may be partly due to an urban/rural bias in the economy-wide measure of capital formation that we employ. Recall, however, that we also found no positive relationship between ACS growth and TFP growth for regional aggregates (Figure 10).

Finally, the coefficient on the logarithm of government expenditure on agriculture is positive and significant. This coefficient indicates that a 10 percent increase in government expenditure on agriculture, all other things being equal, will lead to a 0.34 percent increase in a country's agricultural TFP. This underscores the importance of national government expenditure on agriculture, not only as a means of increasing rates of ACS growth as identified above (Figure 8), but also as a means of contributing to increased productivity *via* technical change and more efficient use of inputs. Of course, even a specific measure of government expenditure on agriculture such as that employed here does not take the composition of this expenditure into account. In a study of ten Latin American countries, López (2005, p. 18) presents econometric evidence that "while government expenditures have a positive and highly significant effect on agriculture per capita income, the structure or composition of such expenditures is quantitatively much more important and also of great statistical significance. […] According to the estimates, a reallocation of just 10 percent of the subsidy expenditures to supplying public goods instead may cause an increase in per capita agriculture income of about 2.3 percent." Hence, a variable that isolates the public good aspect of government expenditures on agriculture, if available, could be expected to have an even higher estimated impact on agricultural TFP growth than that measured here.

## 5. CONCLUSIONS

**(1) The fixed capital stock (ACS) in primary agriculture has been growing steadily at the global level over the last three decades, although for most of this period at declining rates.** Using a volume approach with country-specific constant values per asset to measure the ACS, the average annual rate of worldwide ACS growth fell from 1.1 percent between 1975 and 1990 to 0.5 percent between 1991 and 2007. This reduction was recorded in both developed and developing countries, although the rates of ACS growth were considerably stronger in developing countries than in developed countries in both sub-periods. In the latter group, growth rates have even been negative since the mid-1990s. Most recently, this trend seems to have been reversed. Since reaching a point close to stagnation in the mid-nineties, global ACS growth rates have started to gradually increase, reaching 0.5 percent annually in 2005-07. The reasons for this slight acceleration of capital growth need to be further examined (e.g. has new demand for bio-energy played a role). If ACS growth rates continue to improve, this may signal improving prospects for the world's aggregate capacity to meet future demand. Since the data for 2007 are based on projections and data for 2008-09 are not yet available, it is not possible to determine what impact the food price crisis of 2007-08 had on rates of ACS accumulation worldwide or in developing as opposed to developed countries.

**(2) A shift in the relative shares of capital formation between different regions and country groups appears to be taking place. The gap between higher rates of ACS growth in developing and lower rates in developed countries is falling.** Whereas ACS shrinkage in the developed countries has slowed, rates of

ACS growth in the developing countries have remained positive but continued to fall. In view of the fact future demand growth is mainly expected in the developing countries, this shift could lead to increasing supply bottlenecks in the import dependent developing countries, unless action is taken to increase investments in these countries.

**(3) Annual rates of growth in the stock of improved agricultural land have been declining at global level.** As a consequence, the share of land, including land equipped for irrigation, in total ACS at the global level (currently at about 50 percent) is gradually declining. This may reflect at least in part a reduction in the willingness to invest in improving the productivity of the existing stock of land, which would be reason for concern especially in many marginal areas where the on-going depletion of natural capital through declining soil fertility is not accounted for.

**(4) The ACS has grown the least in countries with the highest prevalence and depth of hunger.** The majority of the poor and hungry live in rural areas and depend directly or indirectly on agriculture for their livelihood. Therefore, increasing the ACS per person active in agriculture has been an important factor of success in reducing undernourishment. However, in several of the least developed countries, in particular in sub-Saharan Africa and South Asia, the growth of the population active in agriculture has outstripped the rate of ACS growth. This development is particularly worrying because it severely limits these countries' ability to increase labour productivity in rural areas and hence to reduce poverty and under-nourishment. This result is obtained irrespective of the method used to estimate capital stock. By contrast, with few exceptions, the countries making the most progress towards reaching the WFS target of halving the number of under-nourished by 2015 have realized relatively high rates of growth in ACS per worker in agriculture.

**(5) Government expenditure on agriculture is correlated with capital formation in a sample of developing countries.** This correlation between national government expenditure on agriculture and growth in national ACS confirms the decisive role of public expenditure in creating an enabling environment in terms of infrastructure and sustainable access to natural resources that can provide adequate incentives for the private sector, in particular farmers, to invest in productive assets. This should be a strong signal for governments in developing countries to change priorities in budget allocations so as to avoid or at least reduce any existing discrimination against agriculture. Public expenditure on agriculture can be an important ingredient in an investment climate conducive to agricultural development and the reduction of hunger.

**(6) Between 1975 and 2007, annual total factor productivity growth in world agriculture was roughly 1.7 percent.** This average masks important differences between regions, ranging from 2.1 percent in China and 1.7 percent in Transition countries to 1.4 percent in the rest of Asia, 1 percent in Latin America and 0.9 percent in Sub-Sahara-Africa. These differences between regions point to a substantial scope for further productivity growth. The breakdown of TFP growth into efficiency gains and technical change also varies widely between regions. Overall, efficiency gains have contributed relatively little to overall total TFP in the developing countries, although they have played a significant role in the transition countries. This has implications for the entry points of productivity enhancing policies in developing countries.

**(7) Government expenditure on agriculture has a significant positive impact on total factor productivity in a sample of developing countries.** All other things being equal, increasing government expenditure on agriculture by 10 percent leads to a 0.34 percent increase in a country's agricultural TFP. Foreign direct investment is also found to have a positive impact on productivity growth, but only in combination with an institutional environment characterised by efficient bureaucracy, a lack of corruption, and democratic political structures. This suggests that the investment climate in a country – among other things its institutional and governance structures – has an important influence on the type of foreign direct investment that it can attract, and the impact of this investment on the agricultural economy.

**(8) The estimates of ACS levels and growth presented in this paper are based on two different approaches which differ in many respects. Each of these approaches to estimating the ACS is characterised by important strengths and weaknesses, and they do not always produce the same results.** International Organizations such as the FAO should engage in a concerted and sustained effort to refine and reconcile estimates of fixed capital formation, including upstream and downstream sectors and rural infrastructure in developing countries. Efforts should be made to combine the advantages of existing methodologies, and to improve the collection and processing of consistent data.

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# INTERNATIONAL INVESTMENTS IN AGRICULTURAL PRODUCTION[1]

**DAVID HALLAM**[2]

## INTRODUCTION

There has been a recent resurgence of interest in international investment in agricultural land. Purchases and leasing of agricultural land in Africa by investors in various Gulf States for food production in support of their food security strategy have perhaps attracted most attention until now, although these are just one of a variety of actual or planned investment flows with different motivations. Other countries outside Africa are also being targeted and major investments have also been made or are being planned by Chinese and, rather controversially, investors of the Republic of Korea. Investment companies in Europe and North America are also exploring opportunities motivated by potentially high expected returns on investment partly due to higher food prices and especially where biofuel feedstock production is a possibility.

The main driver for the recent spate of interest in international investment in food production appears to be food security and a fear arising from the recent high food prices and policy-induced supply shocks that dependence on world markets for foods supplies or agricultural raw materials has become more risky. Investment in food production overseas is one possible strategic response among others. At the same time, a number of developing countries in Africa are making strenuous efforts to attract such investments to exploit "surplus" land, encouraging international access to land resources whose ownership and control in the past have typically been entirely national.

Not surprisingly, the apparently anomalous situation of food insecure, least developed countries in Africa selling their land assets to rich countries to produce food to be repatriated to feed their own wealthier people has attracted substantial media interest. It has also attracted international concern more generally, including at the recent G8 agricultural ministers' meeting. Some argue that these investments could mark the beginning of a fundamental change in the geopolitics of international agriculture. Certainly, complex and controversial issues – economic, political, institutional, legal and ethical – are raised in relation to food security, poverty reduction, rural development, technology and access to resources, especially land. On the other hand, the low level of investment in developing country agriculture, especially in sub-Saharan Africa, over decades has been highlighted as a matter of concern and the underlying root cause of the recent world food crisis so any possibility of additional investment resources cannot be dismissed out of hand. The focus needs to be on how these investments can be made "win-win" rather than "neo-colonialism".

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### AGRICULTURAL INVESTMENTS IN THE HEADLINES

**Saudi Investors to Put $100m into Ethiopian Farm**
(*Fortune*, 15.4.2009)

**Saudis Set Aside $800m to Secure Overseas Food**
(*Financial Times*, 15.4.2009)

**UAE Stepping Up Agricultural Investment in Sudan**
(*Sudan Tribune*, 7.8.2008)

**Food Is Gold So Billions Invested in Farming**
(*New York Times*, 5.6.2008)

**Land Leased to Secure Crops for South Korea**
(*Financial Times*, 18.11.2008)

**Korea's Daewoo Logistics Leases Madagascar Land for Feed, Fuel**
(*Bloomberg*, 18.11.2008)

**Short of Food? Rent Half a Country**
(*New York Times*, 19.11.2008)

**Pakistan Offers Farmland to Foreign Investors**
(*Reuters*, 20.4.2009)

**UN Warns Of Neo-Colonialism**
(*Financial Times*, 19.8.2008)

**Manufactured Famine: A New Wave of Food Colonialism Is Snatching Food from the Mouths of The Poor**
(*Guardian*, 26.8.2008)

**Dispute Erupts Over Plans to Invest Millions in Rice Farming**
(*Economist*, 23.4.2009)

## RECENT INVESTMENT TRENDS AND PATTERNS

There are no detailed data on the extent of such investments. Available foreign direct investment data is not sufficiently detailed to determine just how much investment in agriculture there has been and what forms it takes. It is therefore difficult to say with any precision whether the recent investments are a totally new development or a continuation of existing trends. UNCTAD's *World Investment Report* for 2009 will however have a focus on agriculture, and country case studies currently being conducted by FAO, UNCTAD and the World Bank should provide some more detailed information regarding the extent, nature and impacts of investments in particular countries. Anecdotal information is available from the media although the accuracy of much of this is questionable. Some information is available from the investors themselves and from those developing countries receiving inward investment, although not too much detail is divulged given the sensitivity of the issues surrounding these investments and the need for confidentiality.

On the basis of the information available, a number of observations can be made regarding recent trends and patterns.

- There does appear to have been an increase in international investments in agriculture in developing countries although the number of actual implemented investments appears to be less than the number being planned or discussed or reported in the media.

- Land under foreign control remains a relatively small proportion of total land areas in most cases.
- The main form of investment is in purchase or long-term leasing of agricultural land for food production.
- Major investors in current investment flows are the Gulf States but also China and Republic of Korea.
- The main targets for investment are countries in Africa but there are also investments in Pakistan, Kazakhstan, Cambodia, and Brazil for example.
- Investors are primarily private sector but governments and sovereign wealth funds are also involved.
- Private sector investors are often investment or holding companies rather than agro-food specialists which means that necessary expertise for managing complex large-scale agricultural investments needs to be acquired.
- Private sector investors are often funded by government or sovereign wealth funds, making it difficult to separate them out and judge the extent of public sector involvement.
- Sovereign wealth funds seem to be playing a lesser role than had originally been thought although they do appear to have been diversifying their portfolios to include developing country investments and in agriculture.
- In host countries it is governments who are engaged in formulating investment deals.
- Recent investments emphasise production of basic foods, unlike foreign direct investment (FDI) in agriculture in the past.
- Investments include production of animal feed to meet the rising demand for livestock products.
- More traditional FDI continues – in horticulture and flowers in East Africa, for example – but emphasising various forms of joint ventures.
- The recent investments involving acquisition of land and actual production are against the trends in FDI more generally.
- There may be some signs of a shift away from Africa and a search for greater local involvement through joint ventures as with FDI in the past.

## INVESTOR MOTIVATIONS

The motivation for these investments depends on the investor – whether private sector or government. Private sector investments can represent portfolio diversification for financial returns. Biofuel production is also an important objective. However, the main reason for the recent spate of interest and which differentiates it from more previous international investments is food security. This reflects a fear arising from the recent high food prices and policy-induced supply shocks that dependence on world markets for foods supplies has become more risky. Investors seek enhanced food security through investment in countries where the land and water constraints faced domestically are not present. However, they also require security of their investments. While the current preoccupation is to buy land since titled ownership of assets is seen as most secure, there are many arguments against this from the point of view of the receiving country. It is also not clear that it is necessary or desirable even for the investing country. Acquisition of land does not necessarily provide immunity to sovereign risk and can provoke political and economic conflict. Other forms of investment such as contract farming and out-grower schemes can offer just as much security of supply.

In any case, land investments are only one strategic response to the food security problems of countries with limited land and water resources and discussion of these investments needs to be set in the wider context of broader strategic discussions of food security problems. There are a variety of other mechanisms, including creation of regional food reserves, financial instruments to manage risk, bilateral agreements including counter-trade and improvement of international food market information systems, which are under active discussion. In the limit, investment might be simply in much-needed infrastructure and institutions which currently constrain much developing country agriculture especially in sub-Saharan Africa. This, together with efforts to improve the efficiency and reliability of world markets as sources of food might raise food security for all concerned more generally through expanding production and trade possibilities.

In some cases where governments are involved, these investments can be similar to official development assistance. Japan is planning to invest in projects to increase food production in developing countries, especially in Latin America, but which might indirectly benefit Japan though increased export availability.

## HOST COUNTRY MOTIVATIONS

Lack of investment has been identified as a fundamental cause of the continuing low productivity and stagnant production of developing country agriculture. FAO estimates that developing countries need an additional $30 billion per year investment to double food production by 2050 (needed to feed growing populations and ensure basic right to food). Most recent estimates are even higher. Public investment resources are limited by budgetary pressures and official development assistance to agriculture has been declining over many years. The private sector in developing countries has tended to have little capacity to fund investment. International investments therefore have a potentially important role to play.

Some countries are making strenuous efforts to attract such investments to exploit "surplus" land currently unused or under-utilized. Selling, leasing or providing concessional access to land raises the questions of how the land concerned was previously being utilized, by whom and on what tenurial basis. In many cases, the situation is unclear due to ill-defined property rights, with informal land rights based on tradition and culture. While it is true that much land in sub-Saharan Africa is currently not utilized to its full potential, apparently "surplus" land overall does not mean land is unused or unoccupied. Its exploitation under new investments involves reconciling different claims. Change of use and access may involve potentially negative effects on food security and raise complex economic, social and cultural issues. There is substantial evidence of such negative effects arising in other contexts – large-scale biofuel feedstock production, for example. Such difficulties at least demand consultation with those with traditional rights to land, and favour alternative arrangements for investments. More generally, issues are raised by the shift in the terms of access to land from traditional and historical to market-based.

One reason land may not be used to its full potential is that the infrastructural investments needed to bring it into production are so significant as to be beyond the budgetary resources of the country. International investments might bring much-needed infrastructural investments from which all can benefit, but at the same time are deterred by inadequate infrastructure.

The financial benefits of asset transfers to host countries may be small, but international investments are seen as potentially providing developmental benefits through technology transfer, employment creation, infrastructural provisions, production increases, food security and export earnings. Whether these potential developmental benefits are actually likely to be realised is a key concern in the current discussion.

## IMPACTS OF INTERNATIONAL INVESTMENTS

Benefits to the receiving country are a major concern. The key question concerns the extent to which benefits from the investment spillover into the domestic sector in a synergistic relationship including with existing smallholder production systems. Benefits should arise from capital inflows, technology transfer leading to innovation and productivity increase, upgrading domestic production, quality improvement, employment creation, backward and forward linkages and multiplier effects through local sourcing of labour and other inputs and processing of outputs and possibly an increase in food supplies for the domestic market and for export. However, these benefits will not flow if investment results in the creation of an enclave of advanced agriculture in a dualistic system with traditional smallholder agriculture and which smallholders cannot emulate.

While international land acquisitions have been relatively little-studied and information on them is scarce there is a lot of knowledge and research on FDI more generally in agriculture. In spite of the particular economic and political dimensions of land acquisitions, the general FDI experience can provide some guidance not only on the likely benefits and pitfalls of land acquisitions but also the pros and cons of different forms of FDI. It is interesting to note that some of the features of the current round of investment in land appear to be contrary to trends in FDI more generally which seems to be favouring various looser contractual arrangements rather than actual acquisition of major assets. Studies of the effects of FDI in agriculture show that the claimed benefits do not always materialise and catalogue concerns over highly mechanized production technologies with limited employment creation effects; dependence on imported inputs and hence limited domestic multiplier effects; adverse environmental impacts of production practices such as chemical contamination, land degradation and depletion of water resources; and limited labour rights and poor working conditions. At the same time, there is also evidence of longer-run benefits in terms of improved technology, products quality and sanitary and phytosanitary standards, for example. In considering the question of the benefits or otherwise it is therefore important to take a dynamic perspective.

Additional political and ethical concerns are raised where the receiving country is food insecure. While there is a presumption that investments will increase aggregate food supplies this does not imply that domestic food availability will increase, notably where food produced is repatriated to the investing country. It could even decrease where land and water resources are commandeered by the international investment project at the expense of domestic smallholders. Extensive control of land by other countries can also raise questions of political interference and influence.

The impacts of such investments are not necessarily confined to the two parties involved. Third countries may also be impacted through any resulting changes in international trade volumes and price variability where, for example a major importer secures food supplies outside the market.

Whether or not international investments lead to broader developmental benefits for developing countries depends crucially on the terms and conditions of the investment agreements and the effectiveness of the policy and legislative frameworks in minimising risks.

## ALTERNATIVE BUSINESS MODELS

Most of the recent investments, actual or planned, have involved purchase or long-term leasing of land. However, there are a number of alternatives which might achieve or even better achieve food security objectives of the investing countries. Alternative business models – various contractual arrangements, for example - can offer just as much security of supply. It is interesting to note that in other contexts, vertical integration tends to be based much more on such arrangements than the traditional acquisition and operation of upstream and downstream assets and activities. The development of East African horticultural production for export by European supermarkets is a case in point. Such looser arrangements are likely to be more conducive to the interests of the receiving country. However, even here, there are likely to be questions as to the compatibility of the needs of the investors with small-holder agriculture and this in turn raises questions about the poverty reduction potential.

What business model is appropriate depends to some extent on what products the investment is intended to produce, the production system and what collateral investments - in infrastructure, for example - are also needed. Investors may favour land purchase or long-term leasing where economies of scale are significant or major infrastructural investments such as roads and ports are needed. Where economies of scale are not significant, contractual arrangements such as out-grower schemes may be just as acceptable to investors and possibly more capable of generating developmental benefits for local producers.

Mixed models are also possible. There are instances of large-scale commercial units, often a privatized former state farm, owned and operated by an international investor with smallholders around it in a symbiotic relationship selling their output under contract to the central company while receiving support in the form of agreed sales, credit and technical assistance. Sugar investments in United Republic of Tanzania are one example of such a development while the creation of a similar model based on so-called "farm blocks" is an objective of government policy in Zambia.

## SOME POLICY IMPLICATIONS

If it is acknowledged that international investment might make a positive contribution to raising productivity in developing country agriculture, the question arises as to what policies might help to maximize the positive contributions while minimising the associated risks. Investing countries can provide policy incentives to encourage and target outward investment. However, the onus to attract investments to where strategic needs are greatest and to ensure that those needs are met falls primarily on the host countries. They also need domestic policy measures to ensure that local agriculture is capable of capitalising on any spillover benefits of investments.

Host countries need to create an environment which is conducive to international investment and reduces the perceived risks. At the same time, national interests need to be preserved. Developing countries have made a great deal of progress in this respect in recent years, liberalizing entry conditions and establishing investment promotion institutions to facilitate inward investment. Some participate in bilateral treaties and other international agreements and conventions for contract enforcement, arbitration and dispute settlements such as the Multilateral Investment Guarantee Agency. However, the lack of clear property rights, especially to land, remains a deterrent to investment in some countries. Lack of adequate infrastructure may also deter some investors although others see provision of infrastructure as a necessary component of their investments.

If the general developmental benefits of international investments are to be realized then appropriate policy, institutional and legislative frameworks need to be in place to guarantee them. Apart from the financial terms and conditions of the investment, provisions may be needed concerning *inter alia* local sourcing of inputs including labour, social and environmental standards, property rights and stakeholder involvement, food security concerns, distribution of food produced between export and local markets, and distribution of revenues. Trade policy is also involved where investors want to repatriate food produced and some countries have offered trade policy exceptions such as agreements not to impose export controls even in times of domestic food crises.

## CONCLUSIONS AND SOME OUTSTANDING ISSUES

Lack of investment in agriculture over decades has meant continuing low productivity and stagnant production in many developing countries. This lack of investment has been identified as an important underlying cause of the recent food crisis and the difficulties developing countries encountered in dealing with it. Additional investments of at least $30 billion annually are needed in developing country agriculture. Developing countries' capacity to fill that gap is limited and the share of official development assistance going to agriculture has trended downwards over the years to as little as five percent. Foreign direct investment has an important potential role to play, therefore in financing agricultural investments in developing countries. In general terms, the apparent recent surge in interest in international investment in agriculture should be welcomed rather than condemned.

The motivation for the recent spate of interest is food security and a fear on the part of certain food importing countries arising from the recent high food prices and policy-induced supply shocks that dependence on world markets for foods supplies has become more risky. The much-publicized "land grab" involving the purchase or leasing of agricultural land in developing countries for food production is just one form of investment. At the same time, a number of developing countries are making strenuous efforts to attract such investments to exploit "surplus" land. Recent developments could mark the beginning of a profound change in the pattern and nature of global food production and land use.

While such investments should not be rejected in principle there are risks for the host developing country and they raise complex and controversial issues – economic, political, institutional, legal and ethical - in relation to food security, agricultural investment, agricultural development and land tenure and transfer. It is important that any international investment should bring development benefits to the receiving country in terms of technology transfer, employment creation, upstream and downstream linkages and so on. In this way, these investments can be "win-win" rather than "neo-colonialism". However, these beneficial flows are not automatic: care must be taken in the formulation of investment contracts and appropriate legislative and policy frameworks need to be in place to ensure that development benefits are obtained. The case for an international code of conduct which highlights the need for transparency, stakeholder involvement and sustainability and emphasized concerns for domestic food security and rural development needs to be explored.

There is an urgent need to monitor the extent, nature and impacts of international investments and to catalogue best practices in law and policy to better inform both host and investing countries. Detailed impact analysis is needed to assess whether an international code of conduct is desirable and what its content should be. The scope for forms of investment other than land acquisition – such as contract farming, out-grower schemes and other joint ventures - and which are more likely to yield development benefits to host countries needs to be evaluated and best practices promoted.

If foreign direct investment is to play an effective role in filling the investment gap facing developing country agriculture, there is a need to reconcile the investment objectives of investing countries with the investment needs of developing countries. Investment priorities need to be identified in a comprehensive and coherent investment strategy and efforts made to identify the most effective measures to promote the matching-up of capital to opportunities and needs.

# CAN TECHNOLOGY DELIVER ON THE YIELD CHALLENGE TO 2050?

**R.A. Fischer, Derek Byerlee and G.O. Edmeades [1]**

## ABSTRACT

This paper focuses on the yield prospects of wheat, rice and maize since these cereals dominate human diet, and since continued yield growth is considered the major route to meeting future global demand for food, feed and fuel. We define for a region farm yield (FY), attainable yield (AY, as reached with the best technology and prudent economics), and potential yield (PY, yield with the best varieties and agronomy and no manageable biotic or abiotic stresses). FY progress is a function of progress in PY and in closing the gap between PY and FY (we express this gap as a percent of FY). Globally wheat and rice annual yield increases (as a percent of current yield) are falling and are now just below 1 percent, while that for maize is 1.6 percent. For rice and wheat, the growth of yields in absolute terms (kg/ha/year) are also falling in developing countries. Global demand modelling to 2050 predicts large real price sensitivity to yield growth rates, with significant price increases if current rates cannot be increased.

FY, PY and yield gaps are examined in more than 20 important “breadbasket” regions around the world. For wheat annual PY progress currently averages about 0.5 percent, and the yield gap 40 percent (range 25 to 50 percent), while for rice PY growth is also about 0.5 percent while the yield gap averages 75 percent (range 15 to 110 percent). Maize is distinctive with a current average PY growth of around 1 percent and a yield gap which ranges from around 30 percent (Iowa, some uncertainty with PY) to over 200 percent (sub-Saharan Africa). A yield gap of 25 percent or less probably implies that FY is approaching attainable yields, AY. Yield gaps tend to be larger in developing countries, and seem to be closing only slowly except in the case of maize in Iowa and major cereals in Egypt.

Prospects for yield gap closing are discussed. A multitude of constraints can reduce FY, ranging from infrastructural and institutional ones bearing upon farm gate costs and prices and farmer skills and attitudes, to diverse technical constraints. The resolution of the latter in turn depends largely on agronomic and breeding interventions (e.g., better resistance to biotic stresses), though these must be resolved in concert with the other constraints if they are to have significant impact in resource-poor farmers’ fields. Yield gap closing must be a priority for maize in sub-Saharan Africa.

Prospects for PY increase are discussed. PY gain is increasingly related to greater biomass production, implying greater efficiency of utilization of solar radiation. Recent progress appears to have raised this efficiency, while the theoretical limit still appears to leave scope for further increase. In addition PY in water-limited situations ($PY_w$) will depend on further harvest index increase. In rice and wheat heterosis offers prospects for yield gain. We remain skeptical of the medium-term prospects of genetic modification (GM) for yield *per se*, especially PY, but recognize that existing GM crops often deliver higher yields because of gap closing benefits (such as reduced pest losses). New molecular tools for selection show promise for increasing breeding efficiency, but the marginal cost of yield gains is likely to rise. Strong private investment in breeding, as seen with maize, could play a bigger global role, accompanied by facilitating policies.

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We recognize in addition the importance of input efficiency and total factor productivity (TFP) for determining real prices, while prices of non-renewables (energy for traction and N fertilizer; phosphorus) are a relevant concern. TFP in agriculture continues to grow, and many examples confirm the general synergy amongst modern input technologies that achieve not only greater yield but also greater resource use efficiency (e.g. N, P, water, fuel, labour). There are also large gaps in input use efficiency that offer much scope for improved crop and resource management to deliver more with less. Investments in research and development, farmers' information and skills, and good policy drive this process, and will determine future success or failure.

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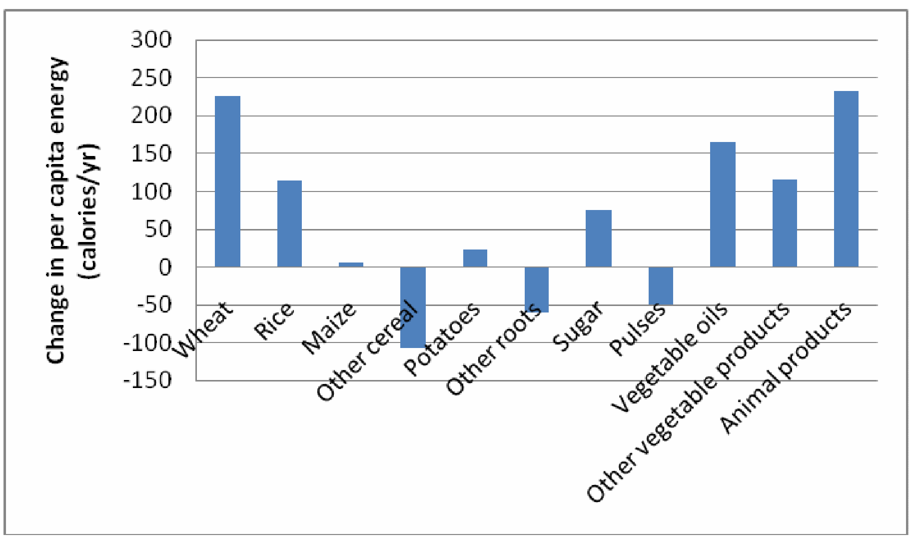
## INTRODUCTION

Projecting crop yields, especially 40 years ahead, is fraught with uncertainty. Yet three stylized facts emerge from several recent studies of world food needs. First, given land and water scarcity, climate change and rising energy prices on the supply side, and growing markets for food, feed and fuel on the demand side, global grain markets will be tighter in the future than over the past 40 years. Second, area expansion will at best be small, so future agricultural growth will be more reliant than ever on raising crop and animal yields. Third, the growth rate of cereal yields has been falling since the Green Revolution years. A major question for this paper is whether this decline means that we are reaching a technological plateau for crop yield, or whether there are still large unexploited sources of yield gains either on the shelf, or in the research pipeline.

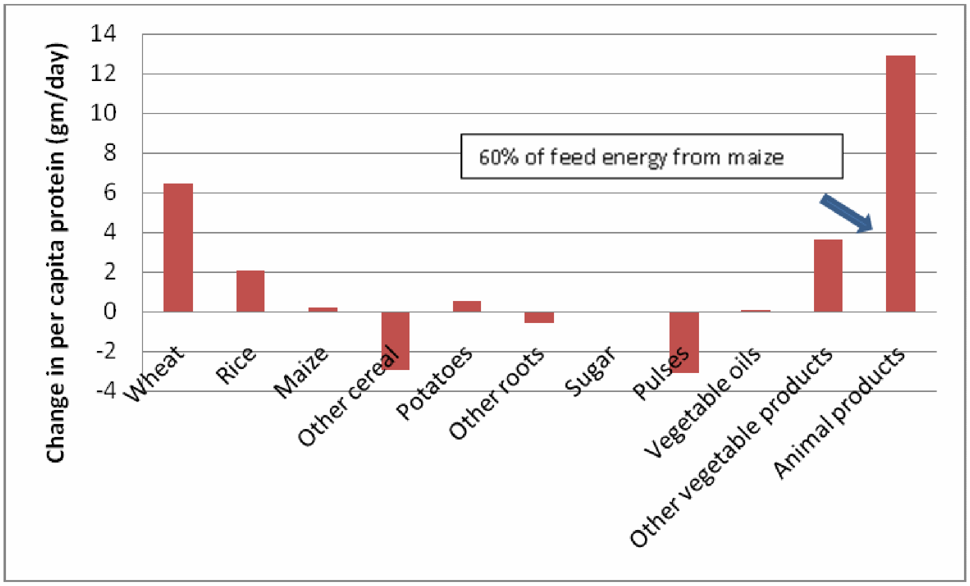
This paper addresses these questions through the analysis of cereal yields and productivity. It does so by tracing recent sources of growth and identifying future technological opportunities in terms of raising the potential yield, as well as closing gaps between existing yields and those that could be economically attainable by farmers. We focus on the big three cereals, rice, wheat and maize. Cereals account for 58 percent of annual crop area and provide about 50 percent of food calories. Rice and wheat alone accounted for about half of the increased per capita energy intake in developing countries since 1960 (Figure 1.1). Maize has been the major source of energy to support the rapid increase in consumption of animal products (Figure 1.2) accounting for over 60 percent of energy in commercial animal feeds, as well as a major feedstock for biofuels in recent years. Together these three cereals will provide about 80 percent of the increase in cereal consumption to 2050 (Rosegrant et al., 2008). However, we also recognize that diversification of food production is needed and a comprehensive review would include relevant data from roots and tubers, pulses and oilseeds. Some of these crops show declining trends, but remain critical to food security of millions, while others such as potatoes, sugarcane, soybeans, canola and oil palm are booming commercial crops serving multiple uses for food, feed and fuel.

**Figure 1.1: Sources of increased per capita calorie consumption, developing countries, 1961-2003**




Source: FAOSTAT

**Figure 1.2: Source of increased per capita protein consumption, developing countries, 1961-2003**




Source: FAOSTAT

The paper uses a bottom-up approach that reviews farm survey and experimental evidence on yields and yield gaps in the world's breadbaskets. This allows us to go beyond the estimation of yield growth by simple extrapolation of aggregate trends to explore the most likely sources of increased yields, both in terms of proximate factors, such as higher yielding varieties, input use and reducing losses from biotic and abiotic stresses, to broader policy and institutional factors that influence crop management. These include input market efficiency, risk management, and information and skills of farmers. Tentatively we pose some of the critical investments and institutional changes that will be needed to realize these changes.

Ultimately we are interested in the potential for sustainable productivity growth since it is the effects of productivity on food prices that have major welfare implications for poor people. This leads us from a discussion of yields *per se* to an assessment of input use and efficiency, and an analysis of trends in total factor productivity. In addition, sustainability is essential to ensure that productivity can be maintained in the face of depleting non-renewable resources, and that production systems do not degrade the environment.

We employ both a global and local approach to assessing crop yields. Changes in global yields are of course important for global food security. In a globalizing world, many countries will increasingly depend on trade to provision their food needs which should encourage production in the lowest cost regions, barring significant trade barriers. However, there are many situations where trade will be inadequate to assure food supplies. The "megacountries," China and India, have little choice but to produce most of their staple foods, especially rice, given relatively small, thin world markets in relation to their huge domestic markets. In Africa too, poor infrastructure, landlocked location, and lack of foreign exchange necessitate that much of the food be produced near where it is to be consumed. The high population growth in some of the more densely populated African countries places additional urgency on accelerating domestic production (e.g. projected population of Ethiopia of 185 million in 2050). The 2008 food price spike induced in part by export bans as well as rising energy costs for long-distance transport will likely lead many other countries to put a premium on local supplies.

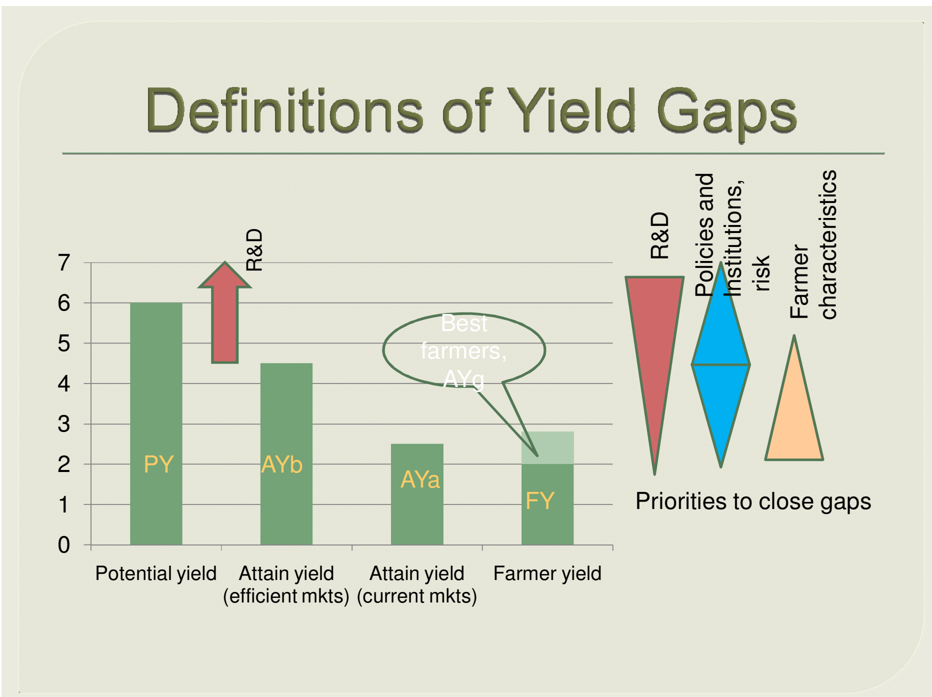
## 2. DEFINING KEY CONCEPTS

There is a rich and evolving literature on various measures of yields and efficiency gaps, yet these terms are often used very loosely. This section defines the measures used in this paper and their interpretation, and relies largely on Ali and Byerlee (1991), Loomis and Connor (1992), Evans and Fischer (1999).

## 2.1 Yields and yield gaps

There are a number of measures of crop yields, which here means weight of grain harvested per unit field area at a standard moisture content (Table 2.1). The starting point is average farm yield (FY), from which we work upwards to attainable yield (AY) and then potential yield (PY). We include water-limited potential yield (PYw) because it is a sensible yardstick where crops receive on average only low to moderate water supplies (say < 75 percent of potential evapotranspiration). For increasing FY, the objective of this paper, both increasing PY (or PYw), and closing the yield gap, are important, and somewhat different interventions operate on these two steps. The overall gap PY to FY is considered in some detail because it is often easier to measure, but the key gap, the economically recoverable yield gap under current economics, is less, being AYa – FY (Figure 2.1; Table 2.1). Another gap AYb -AYa is the attainable yield gap under efficient institutions and markets (AYb), ultimately linked to world prices, less the AYa : this gap is often positive but can be negative where prices are subsidized to help farmers. Note that throughout this paper yield gaps are expressed as a percent of FY, for better comparability with the basis on which demand growth is estimated.

**Figure 2.1: Schematic view of interesting yield gaps and ways to close them**




Progress in potential yields, PY (or PYw the water limited potential yield), through genetic and agronomic research is an important source of yield growth because raising the yield frontier lifts other yields as well—a rising tide that lifts all boats. There is considerable evidence presented in Section 4 of this paper that $\Delta FY/FY \approx \Delta PY/PY$. However, much will also depend on interactions between genotype and management (Fischer, 2009). Generally PY progress has exploited positive interactions between the genetic and agronomic routes for improvement in yield. The increase in yields of semidwarf wheat and rice varieties at higher levels of management is, for example, significantly more than that of the tall varieties they replaced. In advanced systems however yield increase from agronomy alone, and from these positive interactions, appears to be slowing, although the ongoing synergy between increase maize yield potential and plant population is one exception (Evans and Fischer, 1999).

**Table 2.1: Definitions of yield measures**

| Yield | Symbol | Definition | Estimation |
|---|---|---|---|
| Average farm or on-farm yield | FY | Average yield achieved by farmers in a defined region over several seasons | Regional or national statistics, ground or satellite surveys of fields |
| Economically attainable yield given current markets and institutions. | AYa | Optimum (profit maximizing) yield given prices paid/received by farmers, taking account of risk and existing institutions | On-farm experiments or sometimes crop models |
| Economically attainable yield assuming efficient markets/institutions. | AYb | Optimum yield given prices that would prevail in efficient markets with well functioning risk insurance markets | On-farm experiments, or sometimes crop models |
| Potential yield | PY | Maximum yield with latest varieties, removing all constraints, including moisture, at generally prevailing solar radiation, temperature, and day length | Highly controlled on-station experiments or crop models calibrated with latest vars., well monitored crop contests |
| Water-limited potential yield | PYw | Maximum yield under normal rainfed conditions, removing all constraints as for PY except for moisture | Highly controlled on-station experiments or crop models or crop contests |
| Theoretical yield | | Maximum theoretical yield for prevailing solar radiation based on prevailing knowledge of crop physiology and photosynthetic efficiency | An accepted estimate is given by the initial slope of the photosynthesis versus solar radiation response curve discounted for dark respiration |

Both farmer characteristics and system-wide constraints explain these various yield gaps and suggest how they may be closed. In general, yield gaps at the lower end such as AYa – FY are explained more by farmers' access to information and technical skills, while higher order yield gaps reflect opportunities for research as well as broader policy and institutional constraints. Figure 2.1 depicts these overlapping sources of yield gaps.

These various definitions assume that underlying site characteristics, soil, climate and seasonal conditions that are beyond the control of farmers, are uniform across a defined area. In reality regional surveys reveal large variation yields across farmers and fields, around the average FY in part due to site and season differences.[2] Often the distribution is negatively skewed (e.g. Lobell et 2000), but it is not clear how to relate such distributions to the prevailing AYa and PY. One might expect a proportion of farmers to always reach AYa, and a few to reach PY; crop contests that measure crop yield properly on sufficient field size (say > 4 ha) usually give very high yields which, in the absence of better sources, we have sometimes taken as the prevailing PY, but it is important to know whether the natural resource base of the winning fields (that part of the field which cannot be changed with good management) is representative of the region. Similarly, experimental stations may be in more favorable sites, so that some of the gap to reach PY can be due to site characteristics. In addition, optimum management is in part a function of seasonal conditions that are not known at the time of decision making, so that part of any yield gap is random—the interaction between management (including variety choice) and seasonal conditions.

As with site differences, prices and institutions faced by farmers can vary even within small areas. These may relate to farm size, differential access to credit and input markets, and local power structures. Thus part of the

[2] This can be called the non-manageable natural resource base of the site. However, this depends on time scale. Drainage, liming and terracing can be considered long-term investments to improve an initially deficient natural resource base.

gap between good farmers and average yields may be due to site characteristics (some random), and part due to differences among farmers in resource constraints and prices.

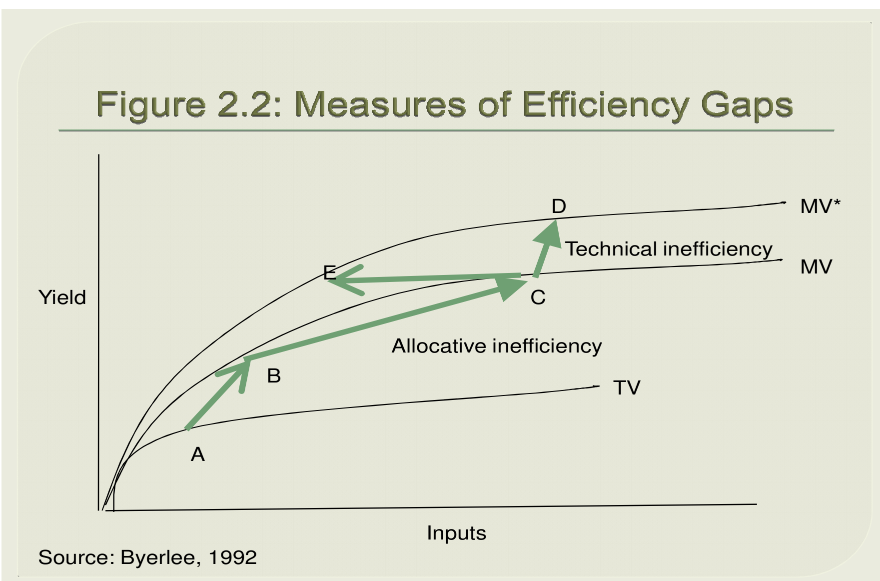
## 2.2 Efficiency and efficiency gaps

For reasons of both productivity and sustainability, we are also interested in efficiency and the prospects of closing efficiency gaps. Put simply, efficiency is measured as the average cost for producing a given yield, relative to the lowest cost option.

Economists generally distinguish technical and allocative efficiency. Technical inefficiency refers to failure to operate on the yield frontier—that is the same yield could be produced by using proportionally less of all inputs. Allocative inefficiency refers to failure to meet the marginal conditions for profit maximization where the marginal value of applying an additional unit of input is equal to the price of the input.

In Green Revolution settings—from Iowa to the Punjab—a useful framework for identifying these inefficiencies and one with considerable empirical support is given in Figure 2.2.[3] During the Green Revolution, farmers adopted modern varieties that shifted their production function from TV (traditional varieties) to MV (modern varieties). At the same time, farmers adopted modest levels of fertilizer and other inputs to reach point B. Initially however, due to risk, lack of knowledge and skills, and resource constraints, farmers did not fully exploit the technology, using inputs at suboptimum levels.

**Figure 2.2 Measures of efficiency gaps (Byerlee 1992)**




The first post-Green Revolution phase was characterized largely by input intensification moving from B to a point C that is closer to the allocative optimum. However, farmers still tended to operate considerably below the production frontier, a measure of technical inefficiency. In the second post-Green Revolution period, the emphasis has been on improving technical efficiency, substituting improved information and managerial skills for higher input use, and moving toward, say, D. Or with appropriate incentives or regulations (e.g. on input pollution), farmers may move to E reducing input use without sacrificing yields. The yield frontier $MV_1^*$ may be defined in terms of the highest production achieved from a given level of inputs in a population of farmers, or it may be defined by reference to a potential frontier based on experimental data. In both cases, similar issues of site specificity and seasonal conditions that influence the measurement of yield gaps also affect the efficiency estimate. Most studies by economists have ignored these site and seasonal conditions, and therefore tend to

[3] For simplicity, these efficiency measures are shown here in one dimension with one input. Technically, their strict definition requires at least three dimensional space with two or more inputs.

overestimate inefficiency (Ali and Byerlee, 1991; Sherlund et al., 2002). Of course, $MV_1^*$ is not static but shifts upward with the release of new technologies, especially newer generations of varieties. It may also shift downward if there are serious long-term problems of resource degradation.

Yield gaps and efficiency gaps are often measuring the same things. However, efficiency gaps may exist even where there are no yield gaps. Farmers may be achieving the economically attainable yield, AYa, but using above optimum input levels. As for yield gaps, factors related to farmer characteristics and system-wide constraints explain variation in efficiency across farmers and fields. Technical efficiency relates largely to timing and technical skills in using inputs and is often explained by farmer specific knowledge and skills. However, system-level factors such as management of irrigation systems can also explain technical inefficiency. Allocative inefficiency can be due to similar factors, as well as differential risks of using inputs, input market failures, and financial constraints.

### 2.3 Total Factor Productivity (TFP)

Ultimately, we are interested in gains in total factor productivity (TFP), as a major determinant of long-term price trends - most productivity increases have been ultimately passed on to consumers through lower prices. TFP is a measure of output in relation to the aggregate of all inputs, whereby changes in agricultural production are decomposed into the component relating to changes in inputs, and a change due to productivity growth. The primarily driver of productivity growth is investment in research and development (R&D) that raises PY. However, research and other factors contribute to TFP growth, such as extension and education, that help farmers close yield gaps, AYa – FY, institutional change or better infrastructure that closes yield gap, AYb – AYa, or related interventions to narrow efficiency gaps, by reducing input costs. Thus TFP is a composite measure of gains in closing gaps.

## 3. SETTING THE SCENE: RECENT TRENDS AND THE CHALLENGE TO 2050

Much of the concern about feeding the world in 2050 relates to the slowing of yield growth in the major cereals over the past three decades (World Bank, 2007). This section briefly reviews global trends in key inputs and cereal yields, and summarizes available evidence on the required growth in yields to meet the world's food, feed and fuel needs in 2050.

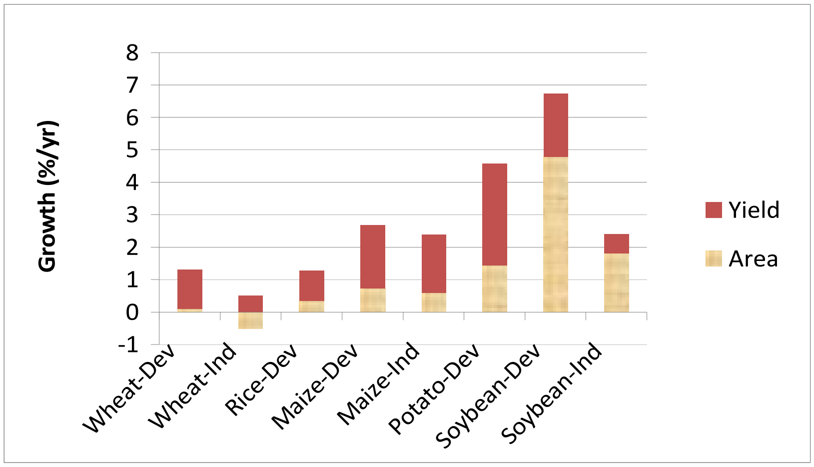
### 3.1 Recent change in crop area and key inputs

Land and water inputs are examined fully elsewhere in the conference, but being critical to our analysis they are mentioned briefly here. Area growth has only been a significant source of production growth in recent decades in Latin America and sub-Saharan Africa. Wheat area has fallen in industrial countries, while rice area has increased at only about 0.3 percent annually since 1990, and is actually falling in China, Republic of Korea and Japan. However, maize area has expanded consistently at over one percent per year in both developing countries (driven by livestock feed) and industrial countries (driven by biofuels, mainly in the United States of America). Even so, yield growth has been the dominant source of production increases even in maize (Figure 3.1).

Other crops have also been dynamic too. Potatoes, traditionally a staple food of much of Europe, are now grown more extensively in developing countries. Due to both area and yield growth, China is the world's largest potato producer. Soybean has been the fastest growing crop, especially in Latin America, driven by demand for feed (Figure 3.1).

The growth of irrigated area slowed sharply in the 1980s and early 1990s (Rosegrant and Pingali, 1994). However, over the past decade irrigated area has expanded steadily at 0.6 percent per annum in developing countries. Given a productivity differential between irrigated and rainfed areas of 130 percent (Fuglie, 2008), irrigation alone accounted for about 0.2 percentage points in overall annual yield growth of 1.1 percent for cereal yields from 1991-2007.

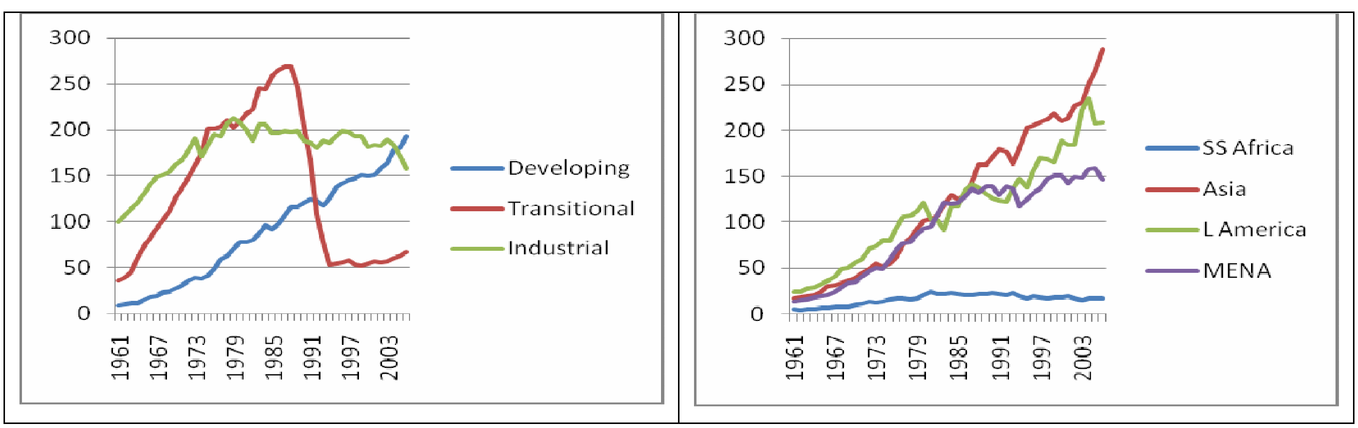
**Figure 3.1: Contribution of area and yield to production growth, 1991-2007**




Increased use of fertilizer has been a major factor explaining perhaps one third to one half of yield growth in developing countries since the Green Revolution (Bruinsma, 2003; Heisey, 2007). Developing countries now account for 68 percent of total fertilizer use. Its use has continued to increase by 3.6 percent per year over the past decade, which would still account for a significant share of yield growth.[4] Using a measure of agricultural area standardized for land quality (Fuglie, 2008), fertilizer use per irrigated-equivalent hectare is also now higher in developing countries than in industrial countries (Figure 3.2).[5] Globally, fertilizer use has plateaued due to a decline in fertilizer use in industrial countries, and a dramatic fall in the countries of the former Soviet Union after those countries moved toward a market economy.

Within developing country regions, the increase in fertilizer use has been surprisingly consistent across most regions. Asia still has the highest and the fastest increase, but fertilizer use intensity is comparable in Latin America and the Middle East/North Africa too. However, fertilizer use per ha in sub-Saharan Africa is abysmally low for reasons such as high prices and poor markets that have been well documented (Morris et al., 2007). Low fertilizer use explains a large part of the lagging productivity growth in that region.

**Figure 3.2: Trends in Fertilizer Use (kg total nutrients per irrigated equivalent ha) by global region, and by developing region (1961-2006)**




Source: FAOSTAT, N+P2O5+ K2O. Irrigated-equivalent area is computed following Fuglie (2008) based on a weighting of the relative productivity of rainfed, irrigated and pasture lands.

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[4] With average rates of fertilizer use on cereals in developing countries of at least 100 kg nutrients per ha (Box 1), current growth in fertilizer use and grain to nutrient response of 5:1 would add 18 kg/ha additional yield annually, or 0.6 percent.
[5] The quality adjusted agricultural area, weights land quality by irrigated, rainfed, and pasture, based on relative productivity, to arrive at a rainfed equivalent area (Fuglie, 2008).

## Box 3.1: Fertilizer Use on Cereals

Wheat, rice, and maize account for about half of all fertilizer consumed globally. Data on fertilizer use for some countries for some years is provided in Table 3.1. The very high rates in some countries such as China suggest little scope for further intensification, and huge scope for improved efficiency. Indeed environmental pressures are likely to lead to pressure to reduce fertilizer use in many countries in Asia.

### Table 3.2: Estimated fertilizer use (kg total nutrients/ha and kg N/ha) for wheat, rice and maize, selected countries, 2006

| | Total nutrients (kg/ha) | | | Nitrogen (kg/ha) | | |
|---|---|---|---|---|---|---|
| | **Wheat** | **Rice** | **Maize** | **Wheat** | **Rice** | **Maize** |
| Bangladesh | | 140 | | | 100 | |
| China | 296 | 310 | 213 | 197 | 192 | 180 |
| India | 164 | 160 | 67 | 117 | 106 | 45 |
| Indonesia | | 108 | 146 | | 93 | 109 |
| Pakistan | 182 | 190 | 161 | 140 | 146 | 123 |
| Philippines | | 53 | 47 | | 46 | 39 |
| Iran | 118 | | | 84 | | |
| Argentina | 77 | | 79 | 44 | | 46 |
| Brazil | 101 | 95 | 127 | 40 | 29 | 49 |
| United States of America | 129 | 250 | 269 | 86 | | 152 |
| EU-15 | 186 | | 373 | 135 | | 227 |
| Poland | 142 | | | 90 | | |
| Sub-Saharan Africa | | 10 | 38 | | | |
| World | 128 | 155 | 153 | 87 | 101 | 98 |

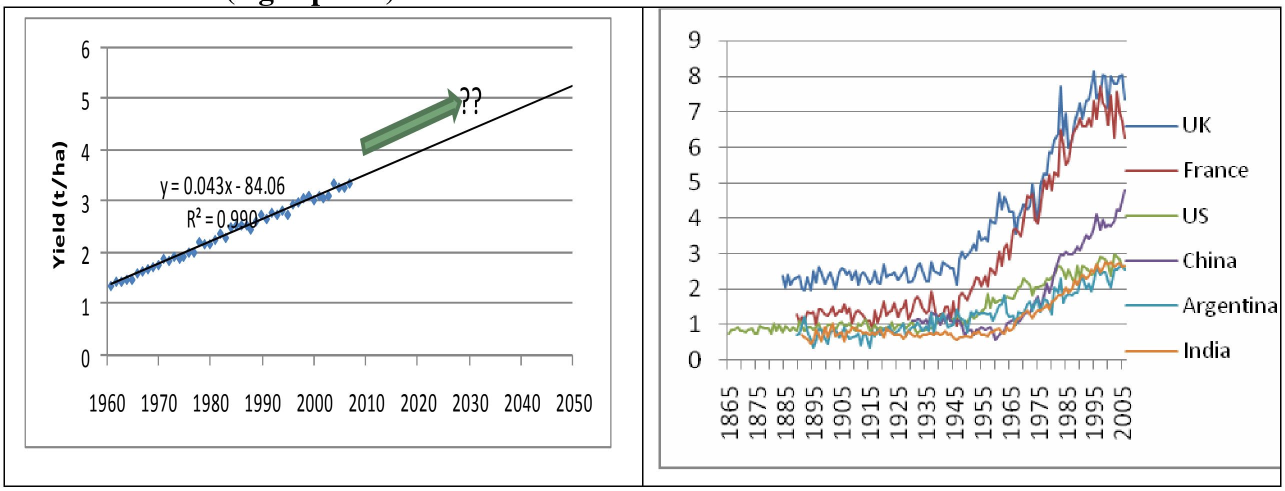
Source: Heffer, 2008; sub-Saharan Africa data from Heisey and Norton (2007) for the late 1990s.

Growth through intensification of fertilizer and irrigation use is no longer important in industrial countries. In addition, fertilizer use and irrigation are already high in some Asian countries, especially China, so that their future contribution to yield growth will be modest at best (Box 3.1). However, there are still major regions of the developing world, especially sub-Saharan Africa, where input intensification is at an early stage. Also Russia, Ukraine and other transitional countries are already reversing the collapse of input use, providing scope for more rapid yield growth in the future.

### 3.2 Recent yield progress (FY)

Over the past five decades, global cereal yields have grown linearly at a constant rate of 43 kg/ha annually and with very low variability around the trend (Figure 3.3). However, this is a sharp departure from relatively stagnant yields in earlier periods (Figure 3.3). Note that linear growth in Figure 3.3 implies declining exponential growth—from 3.2 percent per year in 1960 to 1.5 percent in 2000. Projecting the same linear trend to 2050 would deliver only 0.8 percent per year growth then.

**Figure 3.3: Long-term trends in cereal yields globally (left panel), and wheat yields in selected countries (right panel)**

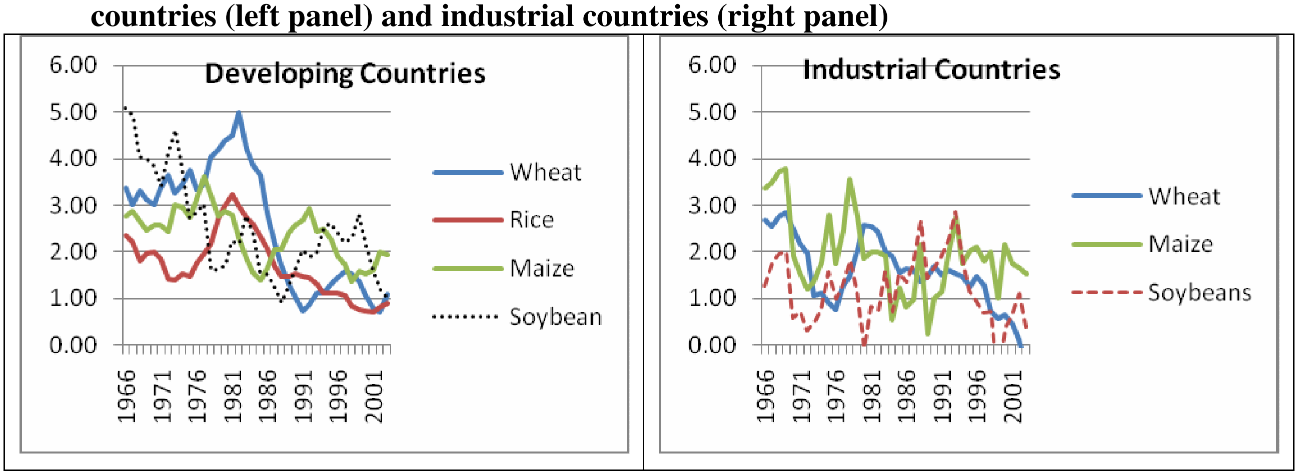



Source: FAOSTAT. Wheat yields updated from Pardey et al. (2007).

The aggregate global picture disguises important differences by region and crop. Developing countries experienced a sharp increase in yield growth with the Green Revolution and then a sharp drop off. The ten-year moving average growth rates for wheat and rice in developing countries has declined from the mid-1980s to about one percent annually in the most recent decade (Figure 3.4). Yield growth of wheat in industrial countries has also slowed and in the most recent decade fell to zero. The trends for maize, although showing some decline in growth rates in both developed and developing countries, are not nearly so pronounced.

At the regional level, Latin America has had the best yield performance for all cereals since 1991, averaging 2.5 percent annually. The lowest have been sub-Saharan Africa and surprisingly East and Southeast Asia, each around 1.2-1.3 percent annually. In one sense, there is some good news in both—sub-Saharan Africa has had a sustained period of modest yield growth from a very low base, and East and Southeast Asia have already have high yields of 4.8 t/ha so even this modest growth rate represents an achievement.

**Figure 3.4: Ten-year moving average yield growth rates, wheat, rice, and maize in developing countries (left panel) and industrial countries (right panel)**




Note: Growth rates estimated by log linear trend regression. Year refers to the mid year of the decade.
Source: Computed from FAOSTAT

There is also evidence of a slowdown in absolute yield growth for rice and wheat. We therefore tested the coefficient, c, of the quadratic term of absolute yield trends by fitting the equation, $y = a + bt + ct^2$, where y is national average yield, and t is year. To reduce the impact of the Green Revolution, the period analyzed was from 1980 to 2007 after modern varieties were widely adopted. The results indicate a clear slowing of the rate of absolute yield gains in rice and wheat. In the case of wheat, this pattern prevails in most regions, and no region shows an accelerating trend. For rice the declining trend is very evident in South and Southeast Asia and South Asia, but Latin America shows an increasing rate of gain.

Again, the results for maize are different showing a linear trend at the global level, and an *accelerating* trend (positive and significant coefficient c) in the developing world. Both South Asia and Latin America show accelerating trends in absolute gains, while only Western Europe shows a declining trend.

In sum, the close linear trend in yield growth at the global level hides considerable heterogeneity in performance by crop and region. Maize has been most dynamic, and among regions, Latin America has been the star, partly because maize is the most important grain in the region. As well as exponential growth rates, looking at absolute growth aids the interpretation of trends.

### 3.3 Scenarios to 2050 and the future yield challenge

Against this background, what rate of yield growth is needed to meet world food needs of the 9.2 billion people that is the projected world population in 2050? Studies by Rosegrant *et al.* (2008) at the International Food Policy Research Institute (IFPRI) and Tweeten and Thompson (2009) provide recent analyses of this challenge.

Global demand and supply prospects will be examined in some depth elsewhere in this conference. Demand for grains is largely determined by population and income growth, with the recent addition of demand for biofuels. At a global level per capita demand for cereals for food is projected to fall in all regions except sub-Saharan Africa as increasingly affluent consumers diversify diets to higher value products, including livestock products. Livestock in turn drive demand for feed grain, especially maize. In addition, maize and to a small extent wheat are used as feedstocks for biofuels. IFPRI projects that this demand for grain for biofuels will continue to increase to 2020-25 before leveling off as second generation technologies based on biomass conversion become available (Rosegrant et al., 2008). Still, by 2020 industrial countries will consume about 150 kg/capita of mostly maize for biofuels, similar to today's per capita consumption of cereals for food in developing countries!

Tweeten and Thompson (2008) provide a simple analysis of what might happen by 2050 with linear growth in yields of major product groups, including cereals. They project an increase in cereal supply of 71 percent over 2000, or a total increase of 1.4 billion t. This derives from projecting the linear annual yield growth of 43 kg/ha suggested in Figure 3.3 over the whole period (1.4 percent growth exponential initially becomes 1.07 percent over the whole period).[6] Their middle estimate of demand growth give an increase of 79 percent by 2050 (1.17 percent exponential over whole period, world population of 9.1 billion in 2050). Thus there will be a projected supply deficit in relation to demand, that implies an increase in weighted real agricultural prices of 44 percent by 2050 to "clear the market".

Using mid-range (baseline) estimates of population (again 9.2 billion by 2050) and income growth, and biofuel demands, Rosegrant et al. (2008) project an overall increase in cereal demand of 1.048 billion t (56 percent) in 2050 from a 2000 base. That implies an average growth of 0.9 percent over the period, but they see demand growth declining from 1.4 percent in the first 25 years to 0.4 percent in the second. Fully 41 percent of this increase is for feed, especially in developing countries. As a result, maize accounts for 45 percent of the increase in cereal demand, wheat for 26 percent, and rice for only 8 percent.

On the supply side, Rosegrant et al (2008) see land and water become increasingly constraining. Area devoted to cereals declines globally by 28 m ha, as loss of crop land and crop diversification in industrial countries and in Asia cancels area expansion in Latin America and sub-Saharan Africa. Water available for agriculture also hardly increases due to competition from non-farm sectors, declining groundwater tables in the bread baskets of India and China, and likely higher energy costs for irrigation (Molden, 2007; Tweeten and Thompson, 2009). Some 60 percent of global cereal production is now from irrigated areas, and with competition within those areas

[6] Tweeten and Thompson assume no change in area, so yield growth is equal to production growth.

for higher value production, projected irrigated area for cereals falls. Maize is the only cereal expected to show modest area expansion.

The IFPRI projections also take account of climate change. However, climate change in the medium projection of the IPCC is not expected to have a significant effect on global yields by 2050 (IPCC, 2007), since yield gains in some regions (mostly temperate) balance losses in other regions (mostly tropical). The impacts of climate change will be addressed in more depth elsewhere in this conference.

The IFPRI yield projections are based on the FAO expert opinions disaggregated by country and agro-ecological zone (Bruinsma, 2003). Overall yield growth in the baseline projection for cereals is 1.0 percent per annum. Averaged for irrigated and rainfed production, the gains are 1.0 percent for wheat, 0.7 percent for rice, and 0.9 percent for maize. FAO projections for 2030 are quite similar (Bruinsma, 2003).

The global average annual absolute rate of yield gain in the Rosegrant *et al*. (2008) projections is 37 kg/ha, 14 percent lower than the linear projection of past performance used by Tweeten and Thompson (2008). Given lower yield growth, the IFPRI baseline projects higher real price increases—91 percent for wheat, 60 percent for rice and 97 percent for maize from a 2000 base. Besides, developing countries will increasingly depend on imports of cereals (and oilseeds) from industrial countries, Eastern Europe (including Russia), and Brazil and Argentina.

Projections are only just that, and the overall results are quite sensitive to the assumptions. In particular, Rosegrant *et al*. show that with a 13 percent increase in public investment over the baseline, especially in R&D, producing a 0.4 percentage point increase in annual yield growth to 1.43 percent, world grain prices would resume their downward trend characteristic of much of the past century and could almost halve the number of malnourished children by 2050. By contrast, a 0.4 percentage point lower yield growth (to 0.61 percent) would lead to a more than doubling of real cereal prices, to around $600/t (US2000 dollars) and stagnation in the number of malnourished.

These studies have two major implications for our analysis of future yield perspectives. First, a continuous linear increase in yields at a global level following the pattern established over the past five decades will not be sufficient to meet food, feed, and fuel needs—that is, future demands at today's real prices or lower. The world will need to do better in the next forty years. Second, the outcome is quite sensitive to yield projections. An increase of 0.4 percent percentage points can reverse price trends. While this sounds like a relatively modest goal, they are exponential growth estimates, and require an increase in current absolute yield growth rate of more than one third. This cannot be taken for granted, especially since aggregate growth rates in both percentage and absolute terms are as we have seen clearly in a declining phase (except for maize) and input growth may make a much smaller contribution than in the recent past.

## 4. SOURCES OF YIELD GAINS IN THE BREADBASKETS

This section reviews recent progress in different measures of yields through a series of case studies in some of the major breadbaskets of the world. The full details of the case studies are reported elsewhere (Fischer et al., forthcoming) and only summary statistics are provided here.

The case studies indicate the depth of analysis which is necessary if we are to understand what is happening currently to crop yield on the farm (FY), which in turn is driven (i) by progress in potential yield (PY) arising from new agronomy and increasingly from new varieties, and (ii) by the adoption of these new technologies which narrows the gap between FY and PY (expressed here as a percentage of FY). Our studies reveal considerable diversity between cases, diversity based largely on crop species, agroecology, and stage of economic development.

In all cases estimates of PY and its rate of change were difficult to estimate, especially for crops under low to moderate rainfall (i.e. PYw), and because it is important that the PY or PYw for a region comes from crops with the same natural resource endowment as the region has on average. The estimates of current PY came from the latest breeders' trials, from simulation models calibrated using the latest cultivars, and sometimes, as a last resort, from yields in crop contests. Estimates of recent PY progress come from comparisons of historic sets of varieties grown inevitably under high inputs, preferably with disease and pest protection, since older varieties often become more susceptible with time. Progress is calculated simply by plotting yield against year of release for varieties released in the last 20 or so years; always relationships were closer to linear over this release period than any other response shape. Note that this represents PY progress under advanced agronomy, and hence contains the genetic gains plus the usually-significant genotype by management interaction gains (Fischer, 2009). PY gains from agronomic innovation alone are thus not included. In advanced cropping systems these are becoming a smaller factor in recent gains, although agronomic innovation remains very important for input use efficiency. In less developed systems the lack of adoption of modern agronomy is often the major cause of the yield gap.

Finally, FY is usually obtained from official statistics and sometimes from surveys. Yield progress for FY is not corrected for global $CO_2$ increase, which for C3 crops like wheat and rice, probably currently adds 0.3 percent per annum to FY progress (Tubiello et al., 2007). However, PY growth estimated from trials of side-by-side comparisons of varieties of different vintage is not inflated by increased $CO_2$.

Several cases from each major crop environment and stage of economic development should be examined if we want to properly sample and fully understand what is behind the aggregate numbers on FY, and to project with some confidence. Some researchers are using high resolution GIS and crop modelling approaches to deal with the challenge of bringing together all of the world's cropping regions (e.g. Harvest Choice, a program that includes IFPRI). But we believe that although we could benefit from a more extensive sampling, our approach is also an appropriate way forward, and we bolster the case study numbers below with other sources of data wherever possible. For illustrative purposes, some key case studies are described more fully below. This lays the basis for the discussion in the following sections of the two paths to further increase FY, namely reduction in the gap between FY and PY, and increasing PY.

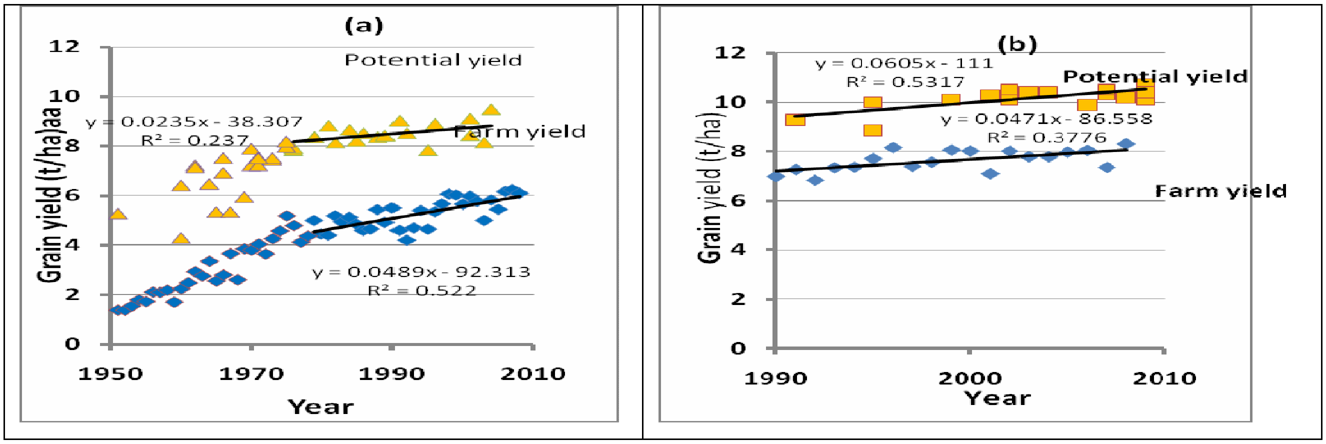
### 4.1 Wheat

Figure 4.1 illustrates two of the better documented case studies with wheat: the Yaqui Valley in Mexico is irrigated low latitude spring wheat (=S1, irrigated or high rainfall spring wheat environment 1) and representative of 22 percent of the world's wheat area, found almost entirely in the developing world, while the United Kingdom is a well-watered winter wheat environment (= W1, winter wheat environment 1), representing 31 percent of the world's wheat area, three quarters of which is in industrial nations (Heisey et al., 2002). The Yaqui Valley has been a major target of the International Maize and Wheat Improvement Center (CIMMYT) and its predecessor's wheat breeding program for over 50 years; it is an environment similar to that for wheat in Pakistan and northwest India, and in Egypt: all have experienced a Green Revolution in wheat yields associated with improved varieties, irrigation and fertilizer.

In the Yaqui Valley, variety turnover is rapid and N rates have now reached 260 kg/ha; despite this, FY progress has slowed to about 49 kg/ha/yr over the last 30 years (Fig 4.1a). However, this should be corrected downwards for a significant and surprising decline in average minimum temperatures over the period, giving progress of only 18 kg/ha/yr or 0.3 percent per year. This is exactly the rate of progress seen in PY. Thus the yield gap is fairly steady at 50 percent of FY, somewhat surprising for a region of moderately-sized farms in a well developed agriculture.

The United Kingdom has one of the highest national wheat yields (just over 8 t/ha), with modern agriculture and an active private (breeding) and public research base. Excellent records of the Home Grown Cereal Authority from their protected variety experiments across the country give a good indication of PY. The rate of FY and PY progress has been fairly steady over the last 20 years at 0.7 percent and 0.6 percent, respectively; N use has been steady at 190 kg/ha for most of the period and the yield gap is also steady (currently 25 percent of FY).

**Figure 4.1:Wheat yield potential and farm yield change in (a) Yaqui Valley of Mexico, and (b) in the UK**
(See relevant case studies for details)




Results of the Yaqui Valley and the UK and all other wheat cases are summarized in Table 4.1. Three other important wheat megaenvironments are included namely low to moderate rainfall spring wheat at low latitude (S4, about 16 percent of world area, equally distributed between industrial and developing countries), low to moderate rainfall high latitude spring wheat (S6, 21 percent of area mostly in industrial countries), and finally low to moderate rainfall winter wheat areas (W4, about 10 percent of area, equally distributed).

Table 4.1 shows a diversity of combinations of key parameters for wheat growing regions. The gaps given can be compared to those in the review by Lobell et al (2009). For wheat, they were able to summarize 12 estimations from developing countries in the 1990s, showing a FY range from 40 to 95 percent of PY, average 65 percent: expressing the gap as a percent of FY it averaged 55 percent, somewhat larger than our estimate for developing countries in Table 4.1. The difference could easily arise both from some lower estimates of FY (understandable give the earlier dates to which FY refers plus the inclusion of less advanced regions) and higher estimates for PY in the Lobell et al (2009) study.

**Table 4.1 Summary statistics[a] for case studies of wheat yield change for case studies**

| Region and mega-environment[a] | Wheat Area M ha | Yield and gap, 2007 or 2008 t/ha, % FY | | | Rate of change, % relative to 2008 yield | | | Comment |
|---|---|---|---|---|---|---|---|---|
| | | FY | PY | Gap | FY | PY | Gap[c] | |
| Yaqui Valley, S1 | 0.16 | 6.0 | 9.0 | 50 | 0.3 | 0.3 | 0 | Case study |
| Punjab, India, S1 | 3.9 | 4.3 | 6.25 | 45 | 0.2 | 0? | 0 | Case study |
| Haryana, India, S1 | 2.4 | 4.2 | 5.75 | 35 | 0.6 | 0? | - | Case study |
| Egypt, S1 | 1.2 | 6.5 | | | 1.6 | | | High FY progress |
| Brazil, S1 | 1.7 | 2.0 | | | 1.6 | | | High FY progress |
| Western Aust., S4 | 4.5 | 1.8 | 2.6 | 45 | 1.4 | 0.5 | -- | Case study |
| N Dakota, S6 | 3.4 | 2.5 | 3.7 | 50 | 0.9 | 1.0 | 0 | Case study |
| United Kingdom, W1 | 1.8 | 8.2 | 10.4 | 25 | 0.7 | 0.6 | 0 | Case study |
| Eastern China W1 | 16 | 4.7? | 7.0? | 50 | | 0.7 | | Zhou et al (2007a,b) |
| Kansas, W4 | 3.6 | 2.6 | 3.9 | 45 | 0.6 | 0.4 | 0 | See case study |

a. FY and its change are from FAOSTAT or USDA NAS. PY sources are given in Fischer et al.,(forthcoming), supplemented by reports from the literature. All rates of FY change are from linear trends over last 20-30 years, and 2008 yields are from linear trends; no curvilinear fits were superior, unless noted. Where possible FY trends have been corrected for secular weather change, but not for increasing CO2.
b. See text for key to megaenvironments.
c. ++ = gap increasing, 0 = no change, -- = decreasing

S1 (irrigated and high rainfall) is the most important wheat environment for the developing world. About 78 percent of the crop is irrigated and was the first target of the green revolution. Several examples are given in Table 4.1. FY and PY progress have slowed markedly in Mexico and India (and South Asia in general) but Egypt, now exceeding the Yaqui Valley in yield, shows remarkable FY progress (discussed under rice), and high rainfall countries like Brazil also have good FY progress; acid soil tolerance and conservation tillage have been an important factor in Brazil's progress.

The environment S4 characterizes rainfed wheat in the Mediterranean region, North Africa, West Asia, Australia and Argentina; it is probably the driest major wheat environment, with Western Australia shown in the Table, an excellent example of this. It is the only one where the yield gap has clearly closed lately, largely because of the adoption of many advances in wheat agronomy.

S6 is the high latitude spring-sown wheat environment of the Northern Hemisphere, comprising 30 percent of the area of the United States of America, most of Canada, eastern Russia, and northern Kazakhstan, along with north eastern China: it is almost entirely rainfed and moderately dry. North Dakota fits S6 and shows modest progress and a yield gap fairly typical of rainfed wheat in the industrial world.

The United Kingdom already discussed is probably reasonably representative of the favourable cool winter habit W1 environment, comprising Europe, Ukraine, southern Russia, the northern China plain and eastern United States of America.[7] In contrast to W1, W4 refers to the drier cool wheat environments, dominated by the Great Plains of the United States of America, the Anatolian Plateau of Turkey, and western China; it is represented in Table 4.1 by Kansas. Low PYw progress and the modest yield gap is similar to rainfed Western Australia. FY progress would likely be similar or better in the W4 regions Turkey and China, because of the lower yield base; also they would have good scope for FY gains from increasing the currently low adoption of conservation tillage in this erosion prone environment.

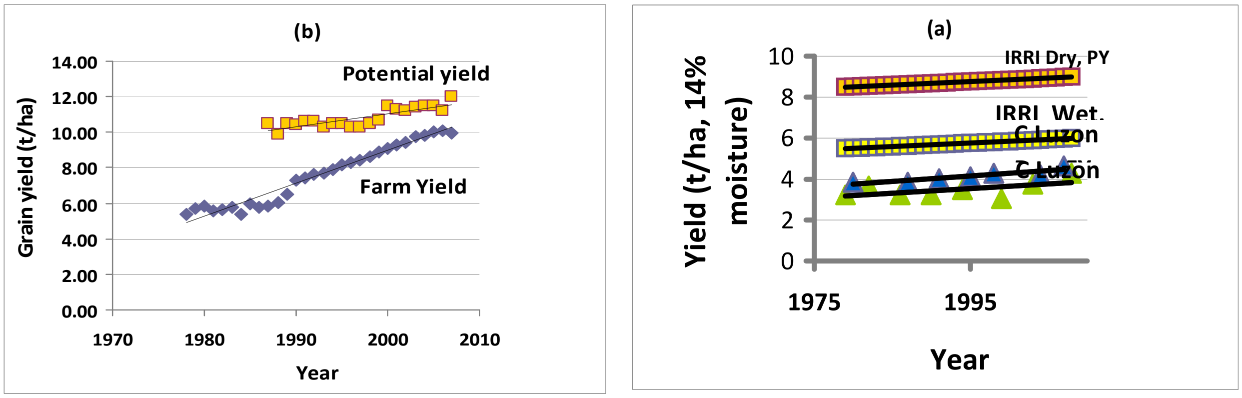
### 4.2 Rice

Figure 4.2 shows two case studies for rice, a crop almost entirely grown in developing countries (except for Japan and Republic of Korea). Central Luzon in the Philippines includes the irrigated wet season (I1, low radiation) and dry season (I2, high radiation tropics) environments which dominate rice production, comprising about 54 percent of world rice area. Egypt represents irrigated rice in the very favourable intermediate latitude high radiation environment (I3), although only one percent of the world's rice area, equally found in industrial and developing countries.

FY in Central Luzon has been surveyed regularly by IRRI over the last 50 years; variety turn over has been rapid and over the last 30 years it has been entirely planted to modern varieties, and has reached high levels of fertilizer application (150 kg/ha N+P+K). After greater initial FY progress with the first modern varieties, yield progress since the late 1970s has been steady at 0.6 percent and a large gap (60 percent wet season, 100 percent dry season) persists when compared to PY at IRRI. The yield gap is smaller (about 35 percent) for wet season crops in Provinces adjacent to IRRI and PhilRice, Laguna and Neuva Ecija, respectively, where FY progress has almost ceased. PY progress itself has been very slow (0.2 percent) in IRRI, although disease and insect resistance, earliness and quality have improved markedly (Peng *et al*. 1999). The current dry season PY of 9 t/ha is corroborated by dry season yields of 9-10 t/ha for optimally-managed irrigated rice in tropical America under the FLAR program (G. Zorrilla, personal comm.). These estimates do not include the new tropical hybrid varieties just reaching farmers in the Philippines, and showing a 11-14 percent increase in PY in the dry season (Yang *et al.* 2007).

[7] However the eastern Chinese portion may have lower PY because of warmer grain filling.

**Figure 4.2 Change in farm and potential rice yields in (a) Central Luzona[a], dry season and wet season, and in (b) Egypt**




a. Potential yields for Central Luzon come from IRRI trials.

Egypt is noteworthy because of the contrast it represents: FY is the highest in the world (10.1 t/ha), exceeding that of California at 9.4 t/ha. FY has shown 1.8 percent growth in the last 20 years or so even as area has increased at 2 percent. PY is growing at only about 0.7 percent, meaning that there has been a marked closing of the yield gap, now at about 15 percent of FY. It is suggested that the situation in Egypt reflects a strong research and extension effort; in addition there was price reform in the late 1980s which removed price disincentives for most crops including rice. These case studies and the others are summarized in Table 4.2.

**Table 4.2: Summary statistics for case studies of rice yield change[a] in key regions**

| Region and megaenvironment[a] | Rice Area M ha | Yield or Gap 2007 or 2008 t/ha, %FY | | | Rate of change, relative to 2008 yield, % | | | Comments |
|---|---|---|---|---|---|---|---|---|
| | | FY | PY | Gap | FY | PY | Gap | |
| Central Luzon wet I1 | 0.8 | 3.8 | 6 | 60 | 0.6 | 0.2 | 0 | |
| Punjab I1 | 2.4 | 3.8 | 8 | 110 | 0.9 | ? | ? | |
| China I1 | 29 | 6.2 | | | 0 | ? | ? | FY growth ceased 1996 |
| Japan I1 | 3 | 6.5 | 10 | 55 | 0.3 | 0.4 | - | Area declining 1.7% |
| Central Luzon dry I2 | 0.4 | 4.5 | 9 | 100 | 0.6 | 0.2 | 0 | |
| Egypt I3 | 0.7 | 10.1 | 11.6 | 15 | 1.8 | 0.7 | -- | Area increase 2% |
| California I3 | 0.2 | 9.4 | | | 0 | | | |
| South Asia R1, R2, R3 | 28.5 | 1.8 | 3.6 | 100 | | | | IRRI, 2008 |

a. FY and its change is average farm yield from FAOSTAT or USDA NAS, PY sources are given in Fischer et al (forthcoming), supplemented by reports from the literature. All rates of FY change are from linear trends over last 20-30 years, and 2008 yields are from linear trends; no curvilinear fits were superior, unless noted.

The irrigated rice environment is well represented in Table 4.2 but it has not been possible to obtain reliable numbers for the other main rice ecologies, namely rainfed lowland (R1, 25 percent of area), rainfed upland (R2, 13 percent of area), and deepwater (R3, 7 percent of area), but Table 4.2 attempts to cover aspects of these for South Asia. Notable in Table 4.2 is the low FY growth, except for Egypt, in particular the low or zero growth of FY in China and Japan (and Republic of Korea, not shown). The situation prevails in China despite the 50 percent adoption of indica hybrids , and the reporting of hybrid yields up to 12 t/ha in the rice bowl of the eastern China plains (Peng et al 2008). Also notable are the slow PY growth rates.

The yield gaps in Table 4.2 can be compared to Lobell et al (2009) who summarized 41 estimates from developing countries of rice FY relative to PY: they ranged from 30 to 85 percent, with an average 60 percent. This converts to a farm to potential yield gap of 65 percent. They supplement these numbers with results from a modelling exercise for irrigated rice PY across Asia, concluding that for north east Asia FY was about 75 percent of PY (gap = 35 percent of FY) but in NW India only about 45 percent (gap = 120 percent).

In the case of rice where the irrigated environments are fairly distinctive and dominant, we get another estimate of yield gaps by simply comparing regional or national yields for like crop agroecologies, and assuming that the highest yield represents at least the current global attainable yield (AY), or at least a conservative estimate of it. For example in I3, the current national average yield in Egypt at 10.1 t/ha: 9-10 t/ha can be seen as the appropriate AY for intermediate latitude countries with cloud-free summers and an absence of chilling at meiosis, as experienced by Iran (current yield 4.9 t/ha), Uzbekistan (3.4 t/ha ), or Chile (5.5 t/ha).

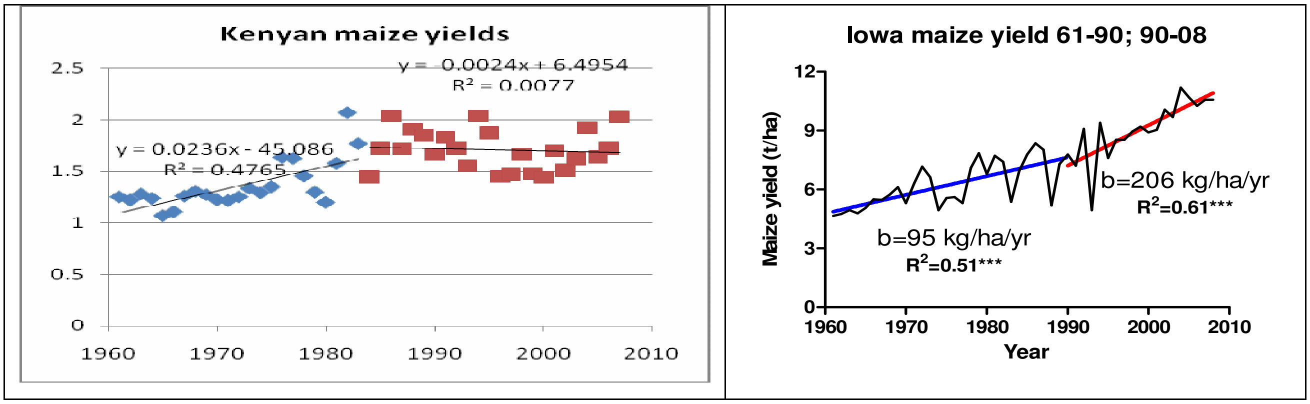
## 4.3 Maize and related crops

CIMMYT has defined useful megaenvironments for maize in the developing world to which we have added the industrial countries. One case study is Kenya which encompasses all the low latitude maize environments, namely tropical lowland (M1, 32 percent of world area), subtropical and mid altitude (M2, 13 percent of area) and highlands (M3, 4 percent); all are to be found in developing countries. Generally these are relatively humid environments with maize tailored to fit the wet season, but being relatively susceptible to water shortage, drought stress is not uncommon: 21 percent and 14 percent of the area in the tropics and subtropics, respectively, are estimated by Heisey and Edmeades (1999) to be "often stressed". The second case study is Iowa in the United States of America, representative of the relatively humid (or supplementally irrigated) favourable temperate environment (M4) which contain 51 percent of the world's maize area, equally distributed between industrial and developing nations.

Maize in Kenya is complicated because of the diverse environments, but 75 percent of the maize is in the more favourable M2 and M3 environments above 1100 meters. Kenya was a pioneer in hybrid maize and other farmer support but this fell away in the early 1980s, and yield growth ceased or even fell after 1980 (Fig 4.3 a). In the 1990s privatization of the fertilizer supply took place and fertilizer use has slowly grown to reach around 45 kg/ha (N+P+K); FY, after falling in the early 1990s, appeared to start growing in the mid 1990s, averaging 36 kg/ha /yr since 1996, to give an impressive 2.1 percent current rate of growth (before the problems of 2008). Many factors still constrain maize yield in Kenya, including degraded soils, insufficient nutrient supply whether from fertilizer or manure, risk associated with drought especially in marginal areas to which maize is spreading, weeds like Striga, and intercropping (which is not in itself a constraint). Thus PY in the favoured M2 and M3 areas is so far above FY (yield gap nationally is at least 200 percent) as to seem irrelevant. However PYw in less favoured parts of Kenya is currently the focus of intensive conventional breeding efforts by CIMMYT and the International Institute of Tropical Agriculture (IITA), and these have shown good progress in trials throughout southern Africa (Bänziger et al , 2006); recently genetic modification (GM) approaches for drought tolerance have been included.

Iowa State grows 5 M ha of maize largely in one-crop per year rotation with soybeans. FY progress has been impressive for many years (Fig 4.3 (b)); progress accelerated around 1990 and currently it is 206 kg/ha/yr or 2.0 percent of the impressive 10.5 t/ha in FY. This reflects a large investment in private sector breeding and public sector research combined with modern farming and a favourable climate: it is also suggested that the recent spurt in progress commenced with the arrival of GM corn varieties. Certainly herbicide-resistant maize favours conservation tillage and perhaps earlier sowing, and Bt maize may be giving resistance against yield losses not even recognized in the past (e.g,, root worm resistance). We struggled to estimate PY and its rate of change: farmer contests suggest PY currently around 17 t/ha, which would give a yield gap of 60 percent, perhaps surprising for advanced farming. The best hybrids in breeders trials appear to be reaching around 12-15 t/ha, so there is some confusion about PY in Iowa, which needs further study. These same breeders trials indicate current PY progress is about 1-1.5 percent per annum (e.g. Hammer et al 2009; Edgerton, 2009).

**Figure 4.3: Changes in maize farm yields in (a) Kenya, and in (b) Iowa State[a]**




a. Maize grain yield (14 percent moisture) Source: (http://www.nass.usda.gov/QuickStats/PullData_US.jsp).

These maize case studies and other useful maize data are summarized in Table 4.3. Some sorghum, millet and soybean data are also included. Sorghum and millet are the poor cousins of maize, tending to grow on the margins of maize areas where it is too dry for maize. Soybeans on the other hand is a unique leguminous oilseed often competing for the maize environment.

**Table 4.3: Summary statistics for case studies of maize yield change in key regions, and for some key related crops**

| Region and megaenvironment | Area M ha | Yield 2007 or 2008 t/ha | | | Rate of change relative to 2008 yield, % | | | Comment |
|---|---|---|---|---|---|---|---|---|
| | | FY | PY | Gap, % | FY | PY | Gap | |
| Maize | | | | | | | | |
| Kenya M1, M2, M3 | 1.75 | 1.8 | 6[b] | 200+ [b] | 2.1 | ++ | -- | FY growth in last 12 yrs only |
| Sub-Saharan Africa M1-M3 | | 1.6 | 4.1[c] | 193[c] | 0.8 | ? | ? | Area increases |
| Brazil M2 | 12.5 | 3.6 | | | 2.6 | | | |
| Iowa M4 | 5.3 | 10.5 | 12?<br>17? | 15?<br>60? | 2.0 | 1.0 | ? | PY from trials versus contests |
| United States of America M4 | 32 | 9.7 | | | 1.5 | | | |
| China M4 | 27 | 5.3 | | | 1.0 | | | Area growth 1.4% |
| Egypt M4 | 0.8 | 8.4 | | | 2.0 | | | |
| Other crops | | | | | | | | |
| Sorghum Africa M2 | 27 | 1.0 | | | 0.4 | | | Area growth 1.7% |
| Millet Africa M2 | 22 | 0.8 | | | 1.0 | | | Area growth 1.3% |
| Millet India M2 | 11 | 0.9 | 1.8 | 100 | 1.7 | | | Area decline -2.0% |
| Soybeans Brazil M2 | 21 | 2.7 | | | 1.8 | | | Area growth 4.4% |
| Soybeans United States of America M4 | 31 | 2.8 | | | 1.3 | | | Area growth 1.5% |

a. FY is from FAOSTAT or USDA NAS. All rates of FY change are from linear trends over last 20 years, and 2008 yields are from linear trends; no curvilinear fits were superior, unless noted.
b. Conservative expert opinion for PY across all environments
c. These are attainable yields (AY) from on-farm with best-bet technologies.

Notable in Table 4.3 are the relatively high FY growth rates, compared to wheat and rice, not only in Brazil, United States of America, China and Egypt, where hybrids dominate, but also some growth in sub-Saharan Africa. Growth in sub-Saharan Africa is from a very low base, as yield gaps remain huge. Egypt since the early 1990s shows what can be achieved in a well-endowed environment with good policy on research, extension and prices.

Again the maize gaps in Table 4.3 can be compared with those in the extensive review by Lobell *et al.* (2009), who cited nine tropical and subtropical maize cases (FY was 16 to 46 percent of PY, average 33 percent), as well as two reports from Nebraska, namely irrigated (56 percent) and rainfed (40 percent); these convert to gaps relative to FY of 200 percent (tropics, subtropics), and 85 percent (Nebraska, irrigated) and 150 percent (Nebraska (rainfed). These numbers are quite comparable to those in Table 4.3, and suggest that yield gaps are large for maize, compared to wheat and rice. But the Nebraska data is surprising and comes originally from Duvick and Cassman (1999). Lobell *et al.* (2009) later cite unpublished simulations of maize PY which indicate FY in Nebraska is 75 percent (irrigated) and 65 percent (rainfed) of PY, amounting to a gap of 35 percent (irrigated) and 55 percent (rainfed) of PY.[8]

In another approach, we can contrast the poor yields in M1-M3 environments in sub-Saharan Africa in Table 4.3 with those of southeast Asia (averaging over 3 t/ha across 8 M ha), and 3.6 t/ha in Brazil.

Yields of sorghum and millet in sub Saharan Africa are even poorer than maize probably partly reflecting area expansion into more marginal areas. In India millet is the direct target of ICRISAT's research effort: yield grows but area declines, while recent simulation modelling and on-farm demonstrations indicate PY to be 1.8 t/ha, suggesting a gap of 100 percent (Murty *et al.*., 2007). Soybeans, the direct competitor with maize, is showing remarkable yield and area growth globally, exemplified by Brazil and the United States of America.

### 4.4 Summary of yield progress and yield gaps

In the wheat and rice examples FY progress is generally below 1.5 percent, and usually below 1.0 percent. PY progress from breeding is no more than 1.0 percent and often much less with wheat and rice, crops where breeders must give more attention to grain quality traits and disease resistance than in the case of maize. In most situations there is a gap exceeding 30 percent between FY and PY, but it is as great as 100 percent in several rice cases. The rate of gap closing has been slow, except in the case of rice in Egypt. For maize FY progress is often 1.5 percent or better, but it has been difficult to get good estimates of PY progress. The gap between FY and PY appears to be large in maize, especially in sub-Saharan Africa where it easily exceeds 100 percent.

## 5. CLOSING EXISTING YIELD GAPS

Yield gaps exist because known technologies that can be applied at the local experiment station are not applied in farmers' fields having the same natural resource endowment. There are many reasons for this, but the first to consider are economics and risk aversion about which there is a rich literature. Farm yields that are constrained only by such considerations have been usefully defined as the attainable yield (AY, see Section 2), but we must bear in mind that AY is driven by farm gate prices, and these may be distorted from world prices by subsidies, taxes, or poor infrastructure and institutions. Of the examples studied in the previous section, wheat yields in the United Kingdom, a nation of modern farmers, institutions and infrastructure, and minimal subsidies nowadays, should approach AY: the 25 percent yield gap seen there between FY and PY (Table 4.1) is therefore one useful estimate of the minimum gap to be expected due to economics and risk. Another approach to AY is to look at the

[8] The discrepancy with the earlier report of 85 and 150 percent gaps comes from lower values of PY with simulation (e.g. 12.2 to 17.6 t/ha across Nebraska, irrigated). Also compared to our estimate of PY for Iowa from contests (Table 4.3) and current yields of contest winning crops in Nebraska, these simulations seem unrealistically low and we hold to the view that there is a substantial yield gap even in Nebraska even with irrigated maize.

distribution of field yields within a region and assume that some proportion of the higher yields indicates AY, e.g. the mean of the top one third (Byerlee et al 1999), or the 9th decile (Yaqui Valley case study). This however has problems - first it is hard to get a large unbiased sample of field yields, and second yield variation may be due to variation in the natural resource base of the fields, not solely to that in exploitable factors.

In our case studies, we found only one yield gap smaller than that with wheat in the United Kingdom, namely 15 percent for rice in Egypt; there appears to be no large price subsidy but there is an especially strong and focused research and extension effort for rice, which is highly concentrated in the Nile Delta region. It is interesting that Lobell *et al*. (2009) also suggest that a gap of 25 percent of FY may represent the economically optimum level of production, while recognizing that risk and uncertainty in farmer decision making (especially in rainfed situations) may raise this estimate of the yield gap somewhat. If we are conservative and consider 30 percent as the minimum, above which there is scope for economic exploitation, then 14 out of the 17 cases shown in Section 4 appear to have an exploitable gap, some being quite large. As might be expected there is also a strong tendency for smaller gaps in industrial countries. Other things being equal, one might expect PY increases to be important for the future where the gap is small, and gap closing possibilities to increase as the size of the gap increases. Here we look at gap closing.

Issues of poor infrastructure, weak institutions and bad farm policy can create huge obstacles to the adoption of improved technologies, which are exhibited, in particular, in price disincentives at the farm gate, expensive credit, and increased risk in general; for example the N to grain fertilizer price ratio in much of Africa is on average double that in other regions of the world, and higher still in inland landlocked regions (Morris *et al*., 1997). Solutions lie with public investment in infrastructure and institutions, and sound policy, the lack of which has been a major contributor to the large yield gap in places like sub-Saharan Africa (e.g. Table 4.3); these have been widely canvassed elsewhere, we focus on those other (non-market) constraints which contribute to the exploitable yield gap (Table 5.1).

The second column (breeding) in Table 5.1 is pointing to ways targeted breeding can help close yield gaps, not by raising PY or PYw, but essentially by making varieties more resilient: since new varieties are generally adopted more readily than new management techniques, often being a less expensive option for the farmer and the extension organization, this is always a favoured route if the required genetic variation exists. In contrast to breeding, there is nothing new in the first and last columns of Table 5.1, these are technologies and policies which already exist in many parts of the world (although some might be refined with further research e.g. IT for small holders or seasonal forecasting), and all have had or should have positive impacts on FY where appropriate.

Without doubt the biggest role of plant breeding in gap closing lies in host-plant resistance. Oerke (2006) presented a meta-analysis of actual yield losses globally due to biotic stress (weeds, insects, fungi, bacteria and viruses) which averaged over 23 percent of estimated attainable yield (hence a greater percent of farm yield) across the major cereals (without any controls, potential losses were estimated to average 32 percent) (Table 5.2). This is part of the exploitable yield gap, and its reduction is the aim of host-plant resistance breeding. Conventional breeding is making progress by maintaining resistance levels in the face of evolving pest agents, while at the same time aiming to strengthen resistances. This has been recently documented globally in the case of wheat rusts (Brennan and Dubin, 2009). Others have pointed to the growing impact of transgenic insect resistance, particularly with maize (and cotton), and linked it to yields gains, as more effective less expensive host-plant resistance replaces insecticides. It would seem that scope for halving a global yield gap of around 30 percent of FY via better host plant resistance is good in the medium term (15 years), especially if transgenic resistance to fungal diseases which currently exist in a few cases, can be delivered.

**Table 5.1: Constraining factors contributing to the farm yield-potential yield gap and their alleviation so that farm yield can approach the attainable yield corresponding to the current potential yield with realistic economics**

| Constraint | Resolution | | |
|---|---|---|---|
| | **Agronomic** | **Breeding** | **Institutional/ infrastructural** |
| **General farmer constraints** | | | |
| Lack of farmer awareness or conviction or skill | On-farm demonstration | On-farm testing and selection | Education, media campaigns, extension |
| Risk aversion by farmer | Forecasts, tactical decision making (e.g., for N top dress) | Tolerance of extreme weather events, like drought, flooding, hail, frost, wind. | Insurance, favorable credit terms |
| Inadequate labour supply | Mechanization, reduced tillage, herbicides | Select for uniform maturity to favour mechanical harvesting | Facilitate labour migration; credit for mechanization |
| **Technical constraints** | | | |
| Lacking major long-term soil amelioration | Drainage, land leveling, liming, deep tillage, gypsum | Waterlogging and salt tolerance | Long-term credit |
| Excess tillage and loss of moisture, soil compaction | Conservation tillage options and suitable machinery, controlled traffic | Suitable varieties: disease and herbicide tolerance | Credit for new machinery |
| Manageable topsoil soil toxicities | Ameliorate (e.g. lime for acidity) | Acid tolerance | Input suppliers, credit |
| Sub optimal nutrient supply | Diagnostics, application of nutrients, tactics | Some scope for improved N, P and Zn uptake and utilization. | Input suppliers, quality control |
| Soil variation within and between adjacent fields | Diagnostics to aid adjustment of application rates | Greater tolerance of soil stresses | |
| Growing old varieties, or use of poor seed | Better on-farm seed management and storage | F1 hybrids and licensed traits to encourage strong seed industry | Strong seed industry and regulation, credit |
| Incorrect time of sowing | Mechanize and reduce tillage to speed sowing. | Make available varieties with range of maturities; herbicide tolerant varieties | Policy to favour mechanization, contract seeding |
| Poor plant population | Better drilling procedures and machines, quality seed storage | More robust varieties (e.g. long coleoptile in wheat, more tillering) | |
| Diseases and pests, above and below ground | Biocides, sanitation, crop rotation. | Host plant resistance | Input suppliers, quality control |
| Weeds | Herbicides, cultivation, sanitation, crop rotation | Enhance crop plant competitiveness, herbicide tolerance | Herbicide quality control, release regulation |
| Poor water management in irrigated systems | Improve water application techniques and skills | Greater tolerance water shortage and excess | Efficient supply systems to farm |
| Long term soil degradation | Crop rotation, fertilizer, green manuring, farm yard manure, conservation tillage, zero tillage | Varieties adapted to biotic and abiotic stresses of high plant residue levels, and with good residue production. | Regulations ensuring land ownership by farmer |

The Oerke (2006) meta-analysis also estimated actual losses due to weeds at ten percent (potential losses 33 percent). Modern varieties tend to be more susceptible to weed competition, so breeding has not helped until the advent of herbicide tolerant cultivars, firstly using natural resistance, then in the last 15 years, GM-based resistance. glyphosate ("Round-up") and glufosinate resistant GM varieties have been very successful in maize, soybean and canola in the Americas, facilitating weed control, conservation tillage and often earlier planting, all leading to somewhat higher yields. GM herbicide-resistance will undoubtedly spread into the rest of the world, but integrated weed management, employing a suite of agronomic and breeding approaches, will remain vital for sustainable weed control and will be a special challenge for developing world extension.

**Table 5.2: Global estimates of potential crop losses without physical, biological or chemical protection, and actual crop losses as a percent of attainable yields of wheat, rice, and maize**

| | Wheat | Rice | Maize | Wheat | Rice | Maize |
|---|---|---|---|---|---|---|
| | Potential losses | | | Actual losses | | |
| Weeds | 23.0 | 37.1 | 40.3 | 7.7 | 10.2 | 10.5 |
| Animal pests | 8.7 | 24.7 | 15.9 | 7.9 | 15.1 | 9.6 |
| Pathogens | 15.6 | 13.5 | 9.4 | 10.2 | 10.8 | 8.5 |
| Virus | 2.5 | 1.7 | 2.9 | 2.4 | 1.4 | 2.7 |
| Total | 49.8 | 77.0 | 68.5 | 28.2 | 37.4 | 31.2 |

Source: Oerke, 2006

In any situation there are usually multiple constraints, and the challenge is to determine which constraints are more critical and more amenable to change while recognizing that interventions often interact positively and are thus most effective when adopted together (de Wit 1992). This can only be achieved by on-farm survey and experimentation. This started many years ago with farming systems research, farm management clubs and rapid rural appraisal, and continues in many guises in the industrial world, especially influenced by the privatization of agricultural extension and nowadays by the use of remote sensing and ICT advances. It is noteworthy that in the industrial world the large commercial maize seed companies such as Monsanto and Pioneer employ more agronomy-extensionist than breeders to ensure that new varieties reach their potential in farmers' fields.

In the developing world the more traditional approaches remain, although with growing emphasis on farmer participation (Paroda 2004). Lobell *et al.* (2009) recount how IRRI conducted on-farm rice experiments in Asia in the 1970s to test high-inputs, learning that farmer yields varied greatly, as did responses to inputs especially fertilizer and insecticide, which were often uneconomic. This pointed to the importance of field-to-field variability, and the need to adjust inputs accordingly and as the season unfolds, whether by site-specific nutrient management, which reached maturity some 20 years later (Dobermann *et al.* 2002), or via field-level pest monitoring as part of integrated pest management packages. Another lesson is surely that this is scientist-intensive expensive research, often taken over by the farmer and his advisers in the industrial world, and explaining why large yield gaps often persist in the developing one, where circumstances demand innovative approaches in order to reach the billion small farmers (e.g. Paroda 2004).

Very recently IRRI again looked at rice yield gaps, this time using expert knowledge to assess constraints and possibilities for rice in South Asia (IRRI, 2008). For this crop, FY is currently 5.1 t/ha over 34.3 M ha; it was estimated that on average yield was constrained 1.9 t/ha (37 percent) by yield limiting factors, which included nutrients (10 percent), diseases (7 percent), weeds (7 percent), water shortage (5 percent), and rats (4 percent). They predicted that the adoption of existing technology and ongoing breeding for robustness over the next 15 years would reduce the total loss by about one third, adding 35 kg/ha/yr or 0.7 percent each year to FY. The exercise was repeated for the 28.5 M ha of rainfed lowland and upland rice in South Asia with a current FY of 1.8 t/ha: yield limiting factors amounted to 68 percent of FY, including nutrients (23 percent), disease (15 percent) and weeds (12 percent); about one quarter of these losses are predicted to be eliminated by R, D and

E (research for development, including extension) over the next 15 years, adding 19 kg/ha/yr, or 1.0 percent, to FY.

With wheat in the Yaqui Valley we have a recent concerted effort to understand the yield gap, PY-FY (currently 50 percent, Table 4.1), this time using the latest high-resolution satellite imagery to estimate field-level yields (Lobell *et al.* 2003) and supplement a long history of farm surveys. It was estimated from images over several years that wheat yields were constrained by late planting (Ortiz-Monasterio and Lobell, 2007), delays in the first post-plant irrigation (Lobell and Ortiz-Monasterio., 2008), and summer fallow weeds (Ortiz-Monasterio and Lobell, 2007). Improved institutions and farm management decisions could largely eliminate these constraints, which averaged over years totaled about 10-15 percent of FY, and would bridge about half of the gap to estimated AY in the Valley. It is interesting the N nutrition was no more than a very minor limitation, surveys and on-farm field work pointing to considerable scope with smarter N management for improved N fertilizer use efficiency, if not greater yield (Ortiz-Monasterio and Raun, 2008).

The persistence of large yield gaps in the developing world especially, draws attention to situations where these gaps have been closed. Rice in Egypt is an obvious example mentioned already. A second example of dramatic technology adoption, albeit with lesser immediate implications for FY than for sustainability of the whole cropping system, relates to the uptake of conservation tillage for wheat, maize and soybeans in southern South America (Argentina, Brazil and Paraguay) (rising from nothing in 1970 to 24 M ha in 2000). This was very much driven by farmer groups and the farmers themselves faced with the threat of serious soil degradation and the opportunity provided by knock-down herbicides and knowledge spill-over from the North (e.g. Ekboir 2002). This revolution has yet to reach other developing continents (but is beginning in north-west South Asia). A third success story amongst small poor farmers has recently appeared with winter maize in Northeastern India and Bangladesh.

We conclude by pointing out that despite individual success stories like rice in Egypt, yield gaps in general appear to be quite persistent and close only slowly; this happens even when gaps are well above that to be expected from economics and risk aversion and even when PY progress has slowed such that catch up through eliminating excessive lags in varietal adoption is not a big issue. The problem is that gap closing on the large scale needed requires massive investments in rural infrastructure and institutions as well as technology transfer, and these are not forthcoming, as maize in sub-Saharan Africa exemplifies. Elsewhere public sector agencies, in particular reaching the billion small farmers in Asia (Paroda 2004), aided by the private sector, in particular in Latin America, have made some inroads on the yield gap; they should continue to do so largely in proportion to the investments made, but there is also scope for innovation, for example based on modern ICT technologies (see Section 7). The employment of agronomists by private seed companies is a pattern that is bound to be followed in the developing world as its seed industry grows in strength and competitiveness. With gap closing, there are no spill-ins as there are in the case of PY advance through R and D, things need to be done locally, but it can be argued that the internet and mobile phones are relevant spill-in technologies that are playing a role which could greatly expand. Finally we point out that given the persistence of yield gaps it remains critically important to continue to lift FY through improved PY, the subject of our next section.

## 6. Increasing Yield Potential (PY)

We have seen that PY has grown substantially in the past through breeding, backed by improved agronomy, and this has driven FY growth. Earlier discussion suggests that in the future, growth in PY is probably going to depend more on breeding than on new developments in crop agronomy. New management by breeding synergies will certainly be discovered but are hard to anticipate. There is a sense that genetic variation for yield must, at some time, become exhausted, and that the relatively easy improvements, such as increases in HI and adaptation of phenology, have already been made. Increasingly progress will probably depend on molecular and physiological knowledge of plant growth processes to better target breeding efforts for PY, although we should not forget that empirical breeding continues to make some yield progress. In this section we consider the prospects and avenues of increased PY under conditions of adequate water and under water-constrained ($PY_W$) conditions. Brief mention is also made of $PY_N$, or PY under nitrogen (N) limitations.

## 6.1 Components of PY

Crop physiologists have developed useful analytical frameworks for exploring potential grain yield and its components under radiation or water limited conditions (Monteith, 1977; Passioura, 1977).

$$PY = \text{Total aboveground dry weight (TDW)} \times HI \quad (1)$$

$$PY = \int PAR_i \times RUE \times HI \quad (2)$$

$$PY_W = \text{Transpiration (T)} \times TE \times HI \quad (3)$$

where $\int PAR_i$ is the integral of photosynthetically-active radiation (PAR, MJ)[9] intercepted by green tissue over the life of the crop; RUE, or radiation use efficiency, is the efficiency with which $PAR_i$ is converted into above-ground biomass (g/MJ). For PYw, T is the amount of water taken up and transpired by the plant (mm); and TE is transpiration efficiency for creating dry weight (mg/g or kg/ha/mm). A parallel to equation (3) for $PY_N$, N-limited potential yield, can be written as N absorbed and NUE. There are many variations of these identities (Mitchell *et al.*, 1998), but they all point towards efficiency with which a limiting input (radiation; water, N) is captured, then used to create dry weight and how efficiently that biomass is converted to grain (HI). The concept of PY/day is also important, since in tropical rice for example, PY has remained static while varieties have become earlier resulting in a gain in PY/day (Peng *et al.*, 1999).

Progress in PY through agronomy has largely come through better crop nutrition, especially N nutrition, giving greater leaf area of longer duration, hence increased $PAR_i$ and modest increases in RUE (Muchow and Sinclair, 1994; Bange *et al.*, 1997). Altered planting date or planting configuration also give small gains in PY and $PY_W$ through better crop timing with respect to expected weather patterns. Progress in breeding for increased PY over the past 50 years has been very significant, and is generally attributed to increases in HI, often via shorter stature in wheat, rice and tropical maize (e.g., Johnson *et al.*, 1986). An exception is temperate maize adapted to the US, where HI has remained relatively stable under favorable conditions and PY has increased because TDW has increased (Duvick, 2005). Typical values of HI are 0.5 – 0.55 under good conditions for modern winter wheat, rice and temperate maize varieties, but only 0.4 – 0.45 for spring wheat and modern tropical maize varieties (Johnston et al., 1986; Duvick *et al.*, 2004). There appears little scope for further increase in HI beyond 0.5 since the crop needs a stable structure to distribute its leaf area, to support its seeds, and to prevent lodging. There seems to be scope, however, for a 20 percent increase in HI in spring wheat and tropical maize.

The increase in TDW in temperate maize appears to be related to a number of small changes: more erect leaves (which should give higher RUE), more grains/$m^2$ at high planting density meaning greater sink strength and RUE during grain filling, greater "stay green" meaning more $PAR_i$ in late grain filling, and a general improvement in tolerance to minor stresses such as cool nights, sudden changes in radiation, high plant density, and oxidative chemicals (Tollenaar and Wu, 1999; Duvick and Cassman, 1999)[10]. More recently, early cold tolerance permitting earlier planting has been highlighted (Kucharik, 2008), and Hammer et al (2009) have made the very novel proposition supported largely by modelling that modern hybrids are apparently generating more biomass by capturing and transpiring around 270 mm of additional water from deeper in the soil than their counterparts of 70 years ago. In the case of wheat and rice, however, TDW has increased relatively little through breeding, although there are some reports of increased RUE (see later).

A key aspect of gains in PY in the past has been increased numbers of grains/$m^2$ of land area rather than changes in weight of individual grains (e.g. Bolaños and Edmeades, 1996; Fischer, 2007). Seed number/$m^2$ is related to

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[9] Crop physiologists work with either total solar radiation or PAR, the latter being close to 0.5 times the former wherever sunshine is involved (Mitchell et al, 1998). We use PAR throughout.

[10] Duvick and Cassman (1999) argue that even under irrigation and excellent management, apparently minor but common stresses such as cool nights, sudden changes in radiation as clouds move over the sun, and high temperature on occasions are important. They concluded that yield gains with selection have come about because of better tolerance to these "minor stresses," rather than increase in yield potential *per se*. At modern planting densities (around 100,000/ha) plants are also under substantial stress from crowding.

crop growth rate from 20-30 d before flowering to 10 d after flowering in all three cereals (see later), and to the ability of the variety to partition assimilate to the developing ear (Andrade et al., 2000; Shearman *et al.*, 2006). Rice and wheat varieties with highest PY appear also to accumulate and later translocate larger amounts of temporarily-stored pre-anthesis carbohydrate to the grain (Shearman *et al.*, 2005; Katsura *et al.*, 2007). Grains that are set at flowering must be filled adequately from current assimilate plus stored carbohydrate, and adequate water and N nutrition are essential (Wolfe *et al.*, 1988).

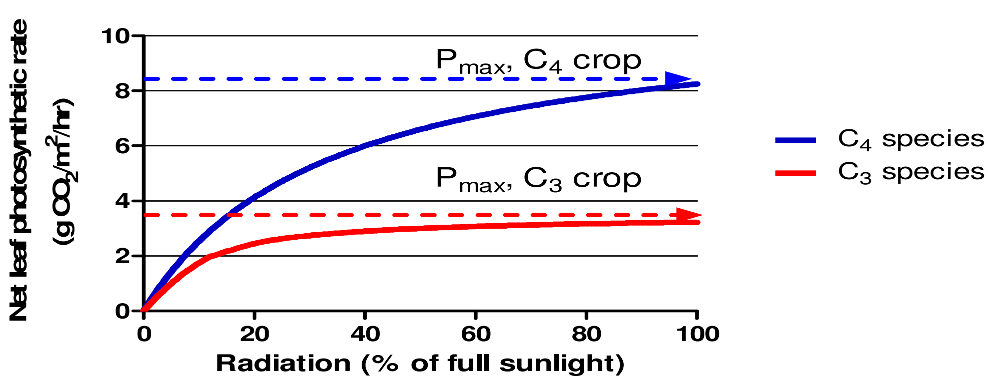
In summary, the likeliest routes to further increases in PY are through increases in RUE, or in $PAR_i$ by extending the active life of leaves, but when it comes to PYw, preventing the common decline in HI when crops are under stress, is also an important possibility. But it is the challenge of RUE and its constituent components that attracts many plant scientists. To quote Duvick (2005), " Finally… maize breeders can always hope for the Holy Grail of plant physiologists, major [increases in RUE], effected without disrupting the rest of the infinitely complicated network of interacting genetic systems…".

### 6.2 Increasing RUE

RUE is the ratio of gross photosynthesis minus (crop respiration + root dry matter) to radiation intercepted over time periods of a few days to the crop's complete lifetime. RUE was initially found to be a relatively stable number and a useful integrator across leaf positions and radiation levels (Mitchell *et al.*, 1998). Crops differ in their photosynthetic systems. Maize has a $C_4$ photosynthetic system that allows its leaves to respond to higher levels of irradiance than the $C_3$ system of wheat and rice, but performs poorly in cool conditions. The $C_4$ system has a $CO_2$ concentrating mechanism in bundle sheath cells (so-called Kranz anatomy) that sharply reduces $CO_2$ losses from the photorespiration observed in $C_3$ crops. As irradiance of the leaf increases, photosynthetic rate of $C_3$ species reaches a maximum ($P_{max}$) at a lower irradiance and at a lower value of photosynthesis than $C_4$ species, and therefore has a lower RUE (Fig 6.1), TE and NUE than a $C_4$ species. $C_3$ species however are generally better adapted to cooler conditions.

The main source of variation in RUE is species themselves, and $P_{max}$ and RUE are positively associated. Although RUE increases relatively less for a given relative increase in Pmax, the exact relationship depends on how light is distributed down into the canopy. Mitchell *et al.* (1998) found that the average RUE values during vegetative growth under optimal conditions were wheat (2.7 g/MJ), rice (2.2 g/MJ), maize (3.3g/MJ) and soybean (1.9 g/MJ), and varietal differences in RUE within crops are quite small. More recent evaluations of RUE in modern maize hybrids result in a value of 3.8 g/MJ, suggesting a possible increase in RUE with selection (Lindquist *et al.*, 2005). Selection specifically for higher leaf photosynthetic rate in several past studies, although sometimes successful, has failed to raise crop yield (Crosbie and Pearce, 1982; Austin, 1989; Evans 1993). Nevertheless, Long *et al.* (2006) suggest a theoretical maximum limit to RUE of 5.8 g/MJ ($C_3$ crops) and 6.9 g/MJ ($C_4$ crops).

**Figure 6.1: Response of leaf net photosynthetic rate to radiation as a proportion of full sunlight for $C_3$ and $C_4$ species (after Loomis and Connor, 1992)**



Since leaves spend much of their lives in shade, the likely route to improving yield potential is to increase RUE under radiation levels of 10-50 percent full radiation (Figure 6.1). RUE values of 3.9 g/MJ for rice (Katsura et al 2007) and 7.6 g/MJ for maize (Tollenaar and Wu, 1999) grown under low radiation conditions support this contention. Most modern cereal varieties have erect leaves and a high ratio of leaf area/ground area. This results in lower irradiance at the leaf surface and hence a higher RUE, but there is little further scope for improving RUE via canopy structure in these crops since all the modern varieties have very erect leaves. Similarly Loomis and Amthor (1999) concluded that crop respiration is very efficient, with only modest prospects of improvement through targeted selection for low respiration rates.

Future increases in RUE through breeding are therefore likely to be through increases in Pmax; recent evidence suggests Pmax is higher in modern varieties of wheat (Fischer *et al.*, 1998) and rice (Horie *et al.*, 2003), while it has been shown in the United Kingdom that modern varieties of winter wheat have higher RUE; importantly this progress in photosynthesis was measured during the critical period determining seed number. What kind of additional progress could be made by focusing on Pmax itself? One opportunity for dramatic changes in Pmax lies in genetic engineering of the leaf photosynthetic system, especially the central photosynthetic enzyme, Rubisco, by increasing its efficiency to capture $CO_2$, or increasing the supply of $CO_2$ or other limiting substrates to the enzyme. A very ambitious project underway at IRRI involves genetic engineering the $C_4$ pathway into $C_3$ crop rice to improve $CO_2$ supply to Rubisco. Long *et al.* (2006) predict RUE increases at annual rates of one to four percent over the next 10 to 20 years through mechanisms such as these. Other strategies include reducing photorespiration in $C_3$ crops or reducing the thermal sensitivity of Rubisco activase by gene shuffling so that Rubisco remains active at higher temperatures (Salvucci, 2008). We consider these transgenic approaches to have a low chance of success in the medium term because of the complexity of the tasks involved. A less challenging approach could involve a search, for example, amongst primitive wheats and wild relatives for more efficient photosynthetic machinery, bearing in mind that such wheats have already exhibited higher Pmax levels than modern varieties (Evans 1993).

## 6.3 Projections of PY

<u>6.3.1 Wheat:</u> a well-researched estimate of wheat yield potential for the United Kingdom (Sylvester-Bradley *et al.*, 2005; R. Sylvester-Bradley personal comm.) based on reasonable assumptions, including an RUE of 2.8 g/MJ and a HI of 0.6, while deploying stem dry matter as efficiently as possible to minimize lodging risk, resulted in 19 t grain/ha under well watered conditions; this could result in a 50 percent increase in average farm yields to around 13 t/ha by 2050.

<u>6.3.2 Rice:</u> Mitchell *et al.* (1998) predicted that conventional selection could result in a tropical and subtropical rice PY of 11.3 t/ha for IR72 maturity. On the other hand, the application of IRRI's "New Plant Type" principles in the large Chinese "super rice" breeding program has already given a 10-20 percent jump in PY to 12 t/ha in hybrids grown in lowland eastern China (Peng *et al.*, 2008). Sheehy *et al.* (2007) predict yields 50 percent greater than the present 9 t/ha if $C_4$ photosynthesis could be engineered into rice, and the relative advantage could rise as global temperatures increase.

<u>6.3.3 Maize:</u> It is difficult to find consistent PY projections for maize. Chile has the world's highest national maize yield (11.5 t/ha over 130,000 ha in 2005-07) and yields over 20 t/ha are have been observed under irrigation in Chile's central valley (G. Edmeades, unpublished data), but this may be a more favourable climate than the US Corn Belt. As one might expect, this is an issue of great interest in the Mid West of the United States of America. On the one hand Cassman *et al.* (2003) argue that the limit of PY has already been reached under irrigation in Nebraska, as reflected in a stable average yield of contest winners of 18.8 t/ha. Higher yields have been observed in contests since 1975 (21-23 t/ha[11]) but the Nebraska number is an average for the period 1983 to 2002. At the other extreme Monsanto, a leading seed company, has set a goal of doubling farm maize

[11] The highest yield reported in the United States of America NCGA Yield Contests in 2007 was 23.9 t/ha (www.ncga.com/files/pdf/2008CYCNationalWinners.pdf). Contest yields (rainfed) in Iowa and Nebraska also show steady yield progress at yield levels about double the state averages.

yields in the United States of America by 2030 using 2000 yields (8.5 t/ha) as the base, resulting in a FY target of 17 t/ha (www.monsanto.mediaroom.com; Edgerton, 2009); this they will achieve in equal measure through conventional breeding, molecular-aided marker selection and genetic engineering for yield. This is unprecedented breeding progress (2.3 percent exponential, or 3.3 percent linear at the outset, 1.7 percent by 2030), but the issue here is can this be sustained over time, and what would this imply for PY increase to 2030? The PY-FY yield gap in Iowa is currently unclear (Table 4.3), but let's assume a minimum gap of 25 percent: that implies PY will be at least 21 t/ha across the United States of America and somewhat higher in Iowa which currently has a yield 8 percent above the national average. A complication for these projections is the recent paper by Hammer *et al.* (2009) which implies yield and water use are more tightly coupled than previously believed and that there may not be enough water from rainfall to support much higher yields in Iowa, a region usually considered to be relatively free of water stress and operating under PY not PYw.

### 6.4 Water-limited potential yield ($PY_W$)

Equation (3) underlies understanding of PYw progress, despite it limitations (Blum 2009). There has been breeding progress for $PY_W$, but generally at lower absolute and even relative rates than that for PY. Initially progress has derived from better fitting the crops' phenological development to the particular rainfed environments, usually meaning selection for earliness whether it is wheat in a Mediterranean environment or maize in a tropical one. This brings the growth of the crop into a moister period, when TE is higher[12] and reduces the risk of exhausting available moisture before grain filling (maintaining HI). Secondly PYw progress has derived from spill-over of progress in PY (e.g. higher intrinsic HI if maintained under stress improves yield in both equations (1) and (3) above; also higher RUE may also deliver higher TE). Recent analysis of old versus new maize hybrids shows progress in a dry year in Iowa matches that under wetter potential conditions (Duvick and Cassman, 1999), although they claim that this is spill-over of improved stress tolerance with higher PY not spill-over of yield potential *per se*. Such is the importance of two factors, that attempts to study other factors in PYw variation usually correct this for variation in flowering date and PY (Fischer and Maurer 1978; Bidinger *et al.* 1987), but the picture is not so clear cut in rice, with marked specific adaptation to flooded and to rainfed conditions limiting spill-over to favourable environments.

These other factors in performance under rainfed conditions are potentially numerous, including early vigour to cover the soil and enhance T at the expense of soil evaporation (a special advantage of proper soil nutrition under rainfed conditions), osmotic adjustment, leaves with waxiness and with low epidermal water conductance, and deeper roots (Blum, 2009). For example for maize in Iowa, it has been suggested that selection has increased tolerance to stress at flowering (Campos *et al.*, 2004), and significantly increased deep soil water uptake in this crop (Hammer *et al.*, 2009). Also modest gains in $PY_W$ of wheat has been made by selecting for TE directly (Richards, 2004). But many of the putative drought tolerance traits have not proven useful when used as selection criteria, or carry a significant yield penalty under well-watered conditions.

One area of opportunity derives from the fact that cereals, and especially rice and maize, are sensitive to drought at flowering, when a sharp reduction in the numbers of kernels set can occur (Fischer, 1973; 1985; Bruce *et al.*, 2001), inevitably reducing HI. Maize ovaries starved for carbohydrate grow slowly, and the ability of the ovary to be successfully fertilized can be severely reduced. Pollen is also directly affected by water stress at meiosis in rice and wheat, and carbohydrate starvation doesn't explain all of the damage. Selection gains occur when stress is managed to coincide with these critical periods. Indirect selection for rapid ear growth rates in maize under managed drought stress has resulted in improved tolerance (Edmeades et al., 2000). Useful genetic variation (non-GM) in the sensitivity of grain set in wheat to water stress around meiosis has recently been demonstrated (R. Dolferus, personal comm.).

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[2] TE is inversely related to the prevailing vapor pressure deficit (vpd) of the air.

### *6.4.1 Water-limited potential yield projections*

A variation of equation (3) used in Australia (French and Schultz, 1983) states that $PY_W$ = k (ET – 110), where ET is water used in mm and 110mm estimates soil evaporation while k = 20 kg/ha/mm is essentially an average TE across the season multiplied by a good value for HI. This defines an upper limit to PYw of wheat for a given level of ET; for example if average ET for wheat in S. Australia is 300mm, then PYw is 3800 kg or 3.8t/ha (c.f., current national average is about 2 t/ha). This approach is an oversimplification but nonetheless has proved a very useful practical guide to PYw in Australia (Fischer 2009). Yield increase through breeding or agronomy can only come from increases in T (for example by storing more water, developing a more efficient root system or reducing losses through evaporation from soil or by weeds), or from increases in TE or HI. These generally appear to be modest in extent, but added up may lift PYw by 25 percent (Passioura 2002).

Revisiting equation (3), the largest differences in TE are seen between $C_4$ and $C_3$ crops, averaging 159 and 83 g biomass/kg water transpired, respectively (Loomis and Connor, 1992). In a warmer and water-limited world this provides another strategic reason for developing $C_4$ versions of rice, wheat and other crops, though $C_4$ crops are not necessarily more drought tolerant than $C_3$ crops (Ghannoum, 2009). There is probably continued scope for $PY_W$ increase through increasing HI particularly via lessening water shortage-induced reductions in grain number. There is no sign of slowing in recent $PY_W$ progress of around 100 kg/ha (or 5-8 percent) annually that has been achieved under managed drought stress in the field in tropical maize over a 10 year period, mainly through increases in HI, and this selection methodology is currently delivering useful gains in farmers' fields in Africa (Bänziger *et al.*, 2006). Progress for drought tolerance in rice is also encouraging, with a single large-effect chromosomal region (QTL) adding 47 percent to yield under severe drought (Bernier et al., 2007), and pedigree selection under managed stress showing gains of 4-10 percent per year (Venuprasad *et al.*, 2008). Finally, genetic engineering possibilities abound in the literature and will be discussed later.

## 6.5 Exploiting heterosis

Heterosis, present in hybrids and obtained by crossing two genetically dissimilar parents, is considered to be a form of stress tolerance, and is often greater for $PY_W$ than for PY. In general hybrids offer around 15 percent yield advantage over open-pollinated parents in maize, and about 10 percent over inbred parents in wheat and rice (e.g. Bueno and Lafarge, 2009). Hybrids have been widely used in maize for 80 years, and are deployed on about 70 percent of the cultivated area globally. In rice and wheat, both normally self-pollinated crops, the limitation is the poor yield of the female parent line when it is forced to outcross, resulting in expensive seed production. Adoption of hybrids in rice is still quite low except in China where indica hybrids account for 60 percent of the planted area, while in wheat technical issues in seed production have prevented any large scale adoption. We predict that this seed yield constraint will be resolved in the next 10-20 years, probably using GM technology, thus permitting hybrids to take over most of the world's rice and wheat area, although we note CIMMYT's lack of optimism on wheat hybrids (Dixon *et al.*, 2008). Thus wheat, rice and maize yields could rise in a one-off yield increase by ten percent, eight percent and five percent, respectively, as the proportion of hybrids under cultivation approaches 100 percent. Because there is an advantage on-farm to growing fresh F1 hybrid seed every year, hybrids foster a viable commercial seed industry and a superior level of intellectual property protection, thereby creating a positive environment for private investment in crop improvement.

## 6.6 Genetic modification using transgenes

Prospects for augmenting PY by increasing $P_{max}$ and RUE through genetic modification (GM) are currently focused mainly on engineering $C_4$ photosynthesis into rice and possibly wheat, or of modifying Rubisco and Rubisco activase enzymes or other enzymes close to Rubisco. These are formidable technical challenges. Other promising GM routes to higher PY are claimed, but few have been demonstrated in the field, and often the compensatory response among yield components is overlooked. Engineering better abiotic stress resistance (greater $PY_W$) may be easier, though many putative drought tolerance genes reduce yield unacceptably in well-watered conditions or simply fail to deliver in the field. In 2012 Monsanto aims to launch commercial maize hybrids carrying the cold shock protein gene *csp* from *Bacillus subtilis* which functions under drought stress as a protein that protects RNA from degradation and for which there is some credible published field plot data

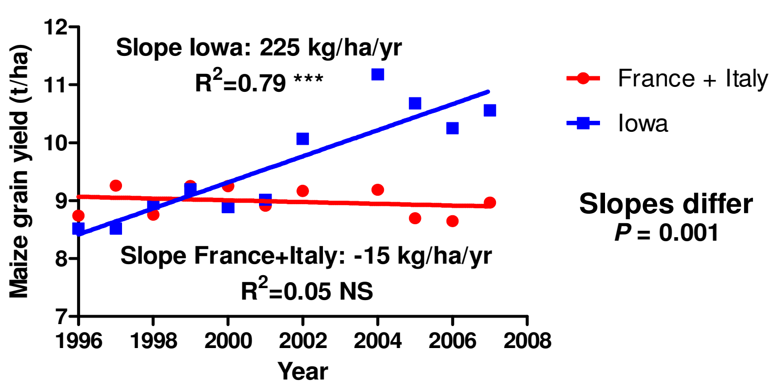
(Castiglioni *et al.*, 2008)[13]. Reports suggest that this transgene is active throughout the life of the maize crop, rather than affecting stress tolerance only at flowering, and will lift yields by six to ten percent under a moisture stress that reduces yields to around 50 percent of the irrigated yield levels (www.monsanto.com). This may mark a major breakthrough for GM breeding targeting abiotic stress and crop yield. Of particular interest is the intent by Monsanto to release this event for use in adapted maize in sub-Saharan Africa on a royalty-free basis through the Water Efficient Maize for Africa (WEMA) Project, in an exciting private-public sharing of cutting edge technology to benefit those who need it the most. Several other recent studies point to possibilities of greater stress tolerance in rice, and rice is the common candidate crop for published work on GM for PY since the genome is sequenced and widely available. However, there are few convincing published reports of yield effects due to transgenes in either wheat or rice (but see Xiao *et al.*, 2009).

Engineering for biotic stress and herbicide resistance has already been hugely successful. It has had a significant environmental effect through reduced pesticide applications, and has lifted yields of crops when under insect attack (Brookes and Barfoot, 2009), but has had little effect on PY *per se*. Engineered herbicide tolerance in soybeans, maize and canola has facilitated conservation tillage and permitted more timely planting, with modest benefits for yield. Transgenic corn root worm resistance in maize has improved $PY_W$ where the insect infestation is severe by retaining more roots and increasing water uptake.

Will GM technology be an important contributor to increases in yield in the future? We believe so. The rate of increase in maize yields in the state of Iowa have been significantly greater than that of France plus Italy since 1996, the year transgenic maize was first introduced to farmers' fields (Figure 6.2). Transgenic technologies are not used in the field in France and Italy, but an estimated 90 percent of Iowa maize carries at least one transgene for herbicide or insect resistance. It is unlikely that unfavorable weather in Europe versus Iowa accounts for all of this difference.

In conclusion, further yield increase via GM for biotic stress resistance and herbicide tolerance is a good possibility; this is yield gap closing. Whether increase will also come from increased PY and PYw *per se* is less certain. However the likelihood of transgenic options for stable and long-lasting disease resistance in rice and wheat in the next 15 years or so has the advantage of sharply reducing the need for maintenance breeding in these two crops, an activity that consumes around 60 percent of the breeding effort currently at IRRI and in the CIMMYT Wheat Program – a much larger proportion than in maize. This would release considerable additional breeding resources to focus on PY in rice and wheat.

**Figure 6.2: Maize yields for 1996-2007 for Iowa and for France + Italy vs. year** (The year 2003 is excluded because of severe drought in Europe)




(Source: USDA and FAOSTAT, 2009)

[13] An earlier GM maize from Monsanto incorporating an *Arabidopsis* transcription factor and showing improved field drought tolerance appears to have been allowed to lag (Nelson *et al.*, 2007).

### 6.7 New tools, efficiency and structures for yield breeding

Conventional plant breeding is a relatively slow, somewhat empirical but very successful process resulting in genetic gains in raised PY and $PY_W$ that have matched demand for grains over the past century. It has depended on large investments in empirical yield testing, and been driven by genetic diversity supplemented by effective wide crossing. Progress has been aided by developments in genetics, population theory, crop and genetic modelling, plot mechanization, robotics, remote sensing, biometry, computing and environmental characterization. Despite this, yield progress through breeding as a percent of current yield, and in an absolute sense, has been declining over the past decades for rice and wheat (Section 4), but apparently not for maize, although gain per unit of investment has probably been declining for some time in maize also (Duvick and Cassman, 1999).

Molecular breeding technologies offer real hope of accelerated progress, provided useful genetic variation continues to be available. These technologies, most notably marker-assisted selection (MAS), marker-assisted recurrent selection (MARS) and transgenics, are now being integrated with conventional breeding approaches, but have not been widely adopted outside of industry leaders in the private sector because of capital constraints. As noted previously, Monsanto, a leading global seed company, has set a goal of doubling maize yields between 2000 and 2030 (www.monsanto.mediaroom.com), calling for gains in yield 2.5 times the historical rate from 1960-2008.

Are such yield gains probable, or even possible? Leading private seed companies are investing considerable resources in maize breeding, blending conventional breeding with MAS, MARS and transgenics, coupled with extensive multilocation testing. Early MARS studies using association mapping suggest that gains in yield in elite germplasm of four percent per year are possible (Crosbie *et al.*, 2006) in favourable and stressed environments, effectively doubling the rate of yield gain compared to conventional breeding (Eathington *et al.*. 2007; Edgerton, 2009). Association mapping is based on dense marker maps, usually using single nucleotide polymorphisms (SNPs) a full-genome marker scan, accurate yield assessment, and statistical algorithms that develop many gene- to-phenotype associations (Heffner *et al.*, 2009). However, the big question is how useful transgenic variation will be in bringing in novel variation to supplement the natural variation for grain yield traits, like RUE, functional stay-green that tolerates drought, for root growth that explores the soil volume more thoroughly, and for some types of drought tolerance. If maize was engineered to tolerate light frosts, this would extend its effective season length in temperate environments, and increase its yield potential; the same would apply to rainfed wheat intermediate latitudes, where frost resistance at flowering would likely bring earlier flowering and significant yield benefits in addition to the conventional and molecular marker assisted gains. These additional GM gains appear technically feasible, but much less certain.

Realizing these additional gains requires that the genetic variation (natural or transgenic) is present and that genotypic (i.e. laboratory assays of genes and markers) and phenotypic data (i.e. field measures of plant performance) can be brought together in the tight time frame demanded by large breeding programs today; physiological understanding will be critical to yield increase via GM, but is less so for MAS and MARS. The latter will depend more on whether methods for detection of gene-phenotype associations and their use within a routine pedigree breeding system, such as “mapping as you go” (Podlich e*t al.*, 2004), deliver on their early promise. Phenotyping capability in the field and greenhouse is expanding much more slowly than our ability to genotype huge arrays of germplasm in the laboratory, and cost per phenotypic data point is declining much more slowly that cost per genotypic datapoint, - yet both classes of data are critical to future success in crop improvement. Improvements in phenotyping efficiency will depend strongly on a combination of carefully managed stress levels in the field and remote sensing of large numbers of plants, again with a bigger role from physiology than in the past. Finally, such changes will likely require significant advances in agronomy, especially in N nutrition, if they are to be exploited fully in the farmer’s field.

Intellectual property (IP) considerations are a constraint to widespread use of molecular breeding techniques, yet it is these that offer the protection that ensures continued private sector investment. IP protection, coupled with use of hybrids, where farmers and companies benefit from annual purchase of seeds, provide a powerful incentive for investment in crop improvement, and are reflected partly in the greater genetic gain seen in maize than in rice and wheat. There are advantages of scale in global breeding, seen initially in the international breeding programs of CGIAR centres like CIMMYT and IRRI and currently in the global operations of multinationals like Monsanto, Dupont, Syngenta and Bayer. Research alliances between SMEs, CGIAR centres and the multinational seed companies addressing needs of national or niche markets have generated viable business models for seed SMEs, needed to maintain a healthy competitive environment in the seed industry.

Transformation and marker-aided backcrossing is now relatively cheap and routine. However the search for appropriate candidate transgenes, IP agreements and royalties, regulatory compliance, and commercialization are expensive undertakings, perhaps costing $50-70 million per gene in industrial countries. The scale of these costs excludes many developing countries and SMEs from this technology, and the recent agreements to waive IP restrictions on the use of technologies associated with high pro-Vitamin A "Golden Rice" and the WEMA Project are welcome signs of corporate social responsibility and public-private collaboration. Regulatory compliance costs have increased greatly in recent years. This reflects societal unease with GM technology, but should reduce in time, as experience reveals the true level of risk. At present, with very few exceptions, that unease has prevented commercial use of transgenes in major food staples. It is safe to assume that by 2050 transgenic technology will still be monitored, but will be cheaper, far more widely available, and used to a much greater extent to improve PY and yield stability of staple food crops.

### 6.8 Concluding comments: Yield potential toward 2050

Prophecy is an uncertain business, and can only be based on extrapolation of existing trends. Needed is an accelerated gain in cereal yields on the farm from less than one percent to around one percent annually: this will largely come from new varieties with increased PY helped by the development of agronomic practices that exploit this new capability while conserving agriculture's natural resource base; in addition new varieties will need to be able to cope with climate change. Areas calling for **increased research investment** are:

- Conventional breeding increasingly aided by genome analysis and other molecular marker-aided breeding focused on increasing PY and $PY_W$, and possibly underlying key mechanisms. This will involve sequencing genomes of a diverse but representative array of rice, wheat and maize genotypes, and must be linked with high throughput precise protected phenotyping facilities, as well as representative production fields with managed input levels (e.g. water supply). Physiology, informatics and biometrics are critical tools here.
- Increased photosynthetic rates, using conventional but targeted approaches, as well as longer term transgenic ones such as developing $C_4$ options for rice and wheat, or otherwise increasing the efficiency of net photosynthesis in warmer environments by modifying Rubisco, Rubisco activase and the enzymes that modulate photorespiration in $C_3$ plants. Since crop plants have finely balanced source: sink interrelationships (Denison, 2007), a major change in source will take several decades of adaptive breeding to deliver its full benefits as grain yield.
- Eliminating outcrossing barriers for successful hybrid production in rice and wheat.
- Crop genetic enhancement through the use of wild species (see Ortiz *et al.* 2008, for wheat).
- Continued focus on stress tolerance as well as PY in all crops will continue the trend towards higher yields, enhanced yield stability, and improved input use efficiency evident in the temperate maize crop today.
- Continued strong investment on protecting genetic and agronomic gains through pest resistance, since climate change will bring changes in the balance of pest and predator. The global soil resource must also be protected from erosion, a huge unfulfilled role for conservation tillage, and from degradation caused by nutrient depletion, an unescapable role for efficient use of chemical fertilizers.

A suitable **policy framework** is needed to attract private investment and to develop technology and guide its benefits to those most in need.

- A strong but balanced emphasis on IP protection for molecular and varietal products and on F1 hybrid production in maize, wheat and rice.
- Societal acceptance of transgenic food products, and reduced costs of transgene deregulation will greatly increase the range of tools at the breeder's disposal.
- Development of a win-win social contract that sees technology outcomes shared with resource-poor countries and sees more private-public partnerships in the developing world. We regard both private and public sectors as key components of efficient international agricultural research, and see a strengthening of the CGIAR system and of regional and global commercial activities as essential complements.

## 7. PRICES, EFFICIENCY AND PRODUCTIVITY

Our ultimate concern is not with yields *per se*, but with improving productivity and reducing prices of food staples. Declining real prices of food staples for 1961-2006 at an annual average rate of 1.8 percent for wheat, 2.6 percent for rice and 2.2 percent for maize in world markets has been a major source of poverty reduction, given that food staples make up a large share of expenditures of the world's poor.[14] This decline in real prices has been driven by growth in total factor productivity, averaging 1.0 percent globally for all agriculture for the period, 1961-2006, but 1.7 percent for the industrial countries who provide most grain exports (Fuglie, 2008). A distinguishing feature of this period has been that TFP has risen faster than prices have declined, so that both farmers and consumers have benefited (Lipton, 2005).

This final section reviews the prospects for sustainable productivity growth and food prices. In particular, we briefly analyze three major determinants of future prices; (i) pressure from rising prices of non-renewable resources and the need for more sustainable systems, (ii) opportunities to close efficiency gaps, and (iii) prospects for continuing gains in TFP.

### 7.1 Prices of non-renewables

Looking out to 2050, the potential for sharply increasing prices of non-renewable resources that have no close substitutes could have major implications for crop yields and food prices. The two resources of most concern are fossil fuels for manufacture of nitrogenous fertilizers and provision of farm power, and reserves of phosphates, an essential macro-element for soil fertility.

#### *7.1.1 Fossil fuels*

All indications are that fossil fuels have entered a new era of higher and more volatile prices with an expected upward trend. Modern agriculture uses an estimated 12.8 EJ[15] of fossil energy or about 3.6 percent of global fossil fuel consumption. This is roughly divided between 7 EJ for fuel and machinery, 5 EJ for fertilizer, 90 percent of which is for N, and the rest for irrigation and pesticides (Smil, 2008). The intensity of commercial energy consumption (nearly all from fossil fuels) varies widely from about 0.14-0.16 GJ/t grain in rice in the Philippines and maize in Mexico in traditional systems, to 2.4 GJ[16]/t for improved rice in the Philippines, 2.5 GJ/t of wheat in Germany and 5.9 GJ/t for irrigated maize in the US (FAO, 2000; Langreid *et al.*, 2004). Both machinery and fertilizer costs are a growing share of production costs in developing countries (World Bank, 2007).

**Nitrogen:** Current global consumption of around 100 Mt of N fertilizer provides over two thirds of N supplied to crops (Socolow, 1999). Although N fertilizer use is now falling in industrial countries, it continues to rise in developing countries (Section 3). Future projections of N fertilizer consumption vary widely from a relatively modest increase to 121 Mt in 2050 (Wood et al., 2004) to 180 Mt in 2070 (Frink et al. 1999), depending on assumptions including N use efficiency.

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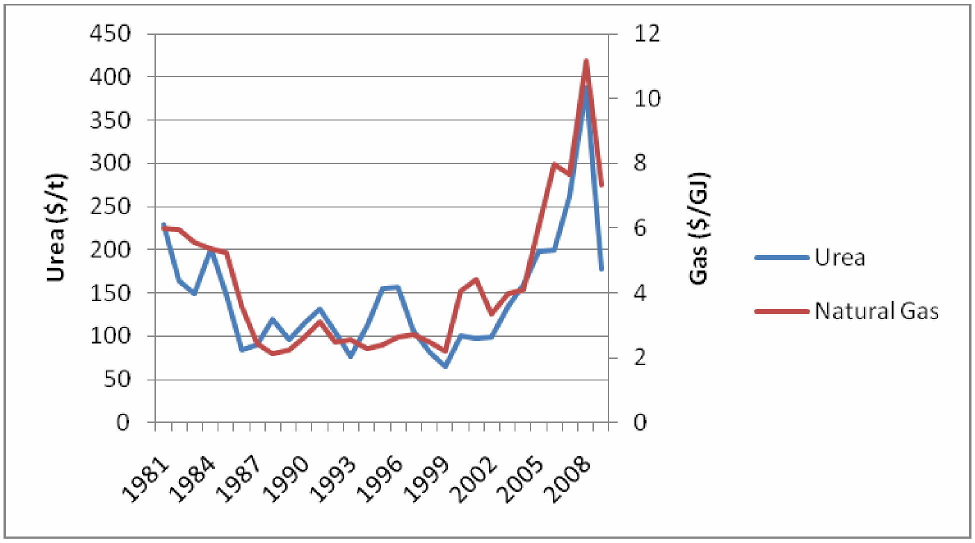
[14] For a review of evidence see World Bank, 2007.
[15] EJ = $10^{18}$ Joules
[16] GJ = $10^9$; 1 litre of diesel contains 38 MJ, 1 ton of maize or wheat about 15 GJ.

Fossil energy (usually natural gas) accounts for 70-80 percent of the cost of manufacturing N fertilizer.[17] Increased efficiency in manufacturing N fertilizer had allowed N fertilizer prices to fall until the 1980s. For example, energy to manufacture ammonia using the best technology at the time has declined from 50-55 GJ/t $NH_3$ in 1950 to 35-40 GJ/t in 1970 to about 27GJ/t in 2000 (Smil, 2008).[18] However, the best plants are now approaching the stoichiometric limit for energy efficiency. Since 1981, N prices have closely tracked energy prices, a ton of urea (46 percent N) costing about 40 times a GJ of natural gas (Figure 7.1) although significant efficiency gains could still be made by mothballing older less efficient plants.

**Figure 7.1: Real price of Urea (bulk E. Europe) and natural gas (Europe) ($US2000)**




Source: World Bank data files

Since the major efficiency gains have already been made, it is likely that the price of N fertilizer will rise in tune with energy prices. In addition, some high income countries are now taxing N fertilizer use as a disincentive to pollution. A tax on green house gas emissions is also likely in the future. This would hit prices of N fertilizer particularly hard due to its fossil energy intensity as well as the fact that upon application it can become a significant source of nitrous oxide, an especially potent green house gas that accounts for about one third of all agricultural greenhouse gas emissions (Crutzen *et al.*, 2008).

Increasing the efficiency of on-farm use of N and the supply of biologically fixed nitrogen are the best options for confronting rising N prices. Numerous studies have documented low on-farm efficiency of applied N, with an average of 33 percent being taken up by the crop, and only 29 percent in developing countries (Raun and Johnson, 1999). Many Chinese farmers may be using N at above optimum levels (Buresh *et al.*, 2004). With better management and lower rates being applied in many cases, N-use efficiency could be improved by 33 percent for irrigated maize to over 100 percent for rainfed rice (Balasubramanian *et al.*, 2004) (Table 7.1). Improvement is already evident in maize in the United States of America for example, where N use per ha has declined through more site-specific application rates, even as yields have increased (Section 4). Precision agriculture provides new tools to further improve efficiency (discussed below). New products such as controlled and slow release fertilizer can also increase efficiency rice (IFDC, 2009). In Bangladesh, over half a million

[17] The actual figure varies based on location and age of the manufacturing plant, the fertilizer product and natural gas costs. Although natural gas is cheap in the Gulf states, fertilizer must still be transported to the point of consumption (A. Roy, pers. comm.).
[18] The conversion of ammonia to urea adds 10 GJ/t N to the energy costs of fertilizer, giving a final energy cost of urea of 55-58 GJ/tN (Smil, 2008).

farmers have adopted Urea Super Granules that are deeply placed at planting time enabling N use to be cut by about one third with a corresponding increase in yields of almost 20 percent (IFDC, 2007). Finally, as plant breeding has raised yield, inevitably it has resulted in more efficient N use (Ortiz-Monasterio *et al.*, 1997; Bänziger *et al.*, 1999; Echarte *et al.*, 2008); this is a general principle which applies to most other inputs (e.g phosphorus, water) as well (de Wit, 1992; Fischer, 2009).

Biological N fixation is the other major opportunity for increasing the supply of N, while reducing the dependence on fossil fuels. Biological fixation already accounts for about one third of world N supply to agriculture, and more in some countries such as Australia. Although legumes only cover about 11 percent of cropped land, there are still important opportunities to fit legumes into even relatively intensive systems, as shown by the adoption of 60-day mung beans on nearly 1 M ha in the rice-wheat system of the Indo-Gangetic plains that has reduced the cost of the following wheat crop by 23 percent (Ali *et al.*, 1997). N-fixation in cereals themselves is also being researched but it is unlikely that this would be a feasible technology by 2050 and the gain in N would have to be balanced against a probable yield penalty for energy diverted to N fixation (Ladha and Reddy, 2000).

**Table 7.1. Mean Recovery Efficiency of N ($RE_N$, percent of N fertilizer applied) for harvest crops under current farming practices and research plots**

| **Crops** | **Mean $RE_N$ under current farming practice (%)** | **Mean $RE_N$ in research plots (%)** | **Maximum $RE_N$ of research plots (%)** |
|---|---|---|---|
| Rice | | | |
| • Irrigated | 31-36 (Asia) | 46-49 | 88 |
| • Rainfed | 20 | 45 | 55 |
| Wheat | | | |
| • Irrigated | 33-34 (India) | 45-57 | 96 |
| • Rainfed | 17 (United States of America) | 25 | 65 |
| Maize | | | |
| • Irrigated & rainfed | 36-57 | 42-65 | 88 |

Source: Balasubramanian *et al.*, 2004 ; Dobermann, 2007

**Farm power:** Conservation farming using zero tillage is a major opportunity to reduce fuel use for farm power in agriculture by an average of 66-75 percent, as well as sequester soil carbon. No-tillage is now used on an estimated 100 M ha globally out of about 1170 M ha of cropped land (FAO, 2008), with a large concentration in the Americas where wide adoption of transgenic herbicide resistant maize and soybeans has strongly accelerated the trend (Brookes and Barfoot, 2008) (Table 7.2). However, there are also good examples from irrigated South Asian systems of wide adoption by small-scale farmers of zero tillage on as much as 5 M ha of wheat in rice-wheat systems, with an estimated savings in fuel costs of 60-90 percent and an increase in wheat yields of 11 percent (Erenstein *et al.*, 2008; Derpsch and Friedrich, 2008).[19] Conservation tillage is also a potentially important source of carbon sequestration in tropical soils (IPCC, 2007).

With less than 10 percent of the world's crop land under conservation tillage, wider adoption of the practice represents a major opportunity to improve the sustainability, energy efficiency and yield of cropping. But conservation agriculture is knowledge intensive and location specific and will require sharply increased investment in research on suitable varieties, management practices adapted to specific sites, appropriate machinery, and advisory services and farmer networks. Current discussion of payments for soil C sequestration

[19] This figure is not included in Table 7.2 since farmers practice tillage in the following rice crop, and so it does not meet the strict definition of zero tillage.

leading up to the Copenhagen summit on climate change, will, if successful, greatly add to the incentive to adopt conservation tillage.

**Table 7.2: Estimated area under no-tillage in major adopting countries (M ha)**

| | 1988-91 | 2003-07 | Percent coverage, 2003-07 |
|---|---|---|---|
| | | | |
| Argentina | 0.5 | 19.7 | 67 |
| Brazil | 1.4 | 25.5 | 38 |
| Paraguay | | 2.1 | 49 |
| Canada | 2.0 | 13.5 | 26 |
| United States of America | 6.8 | 25.3 | 14 |
| Kazakhstan | | 1.8 | 8 |
| Australia | 0.4 | 9.0 | 18 |
| Total[b] | 11.4 | 99.9 | ≈ 9 |

[a] No-tillage is defined as a system of planting crops into untilled soil by opening a narrow slot, trench or band only of sufficient width and depth to obtain proper seed coverage. No other soil tillage is done. (Derpsch and Friedrich, 2008).
[b] Total including countries with under 1 M ha in 2003-07.

Source: FAO, 2008

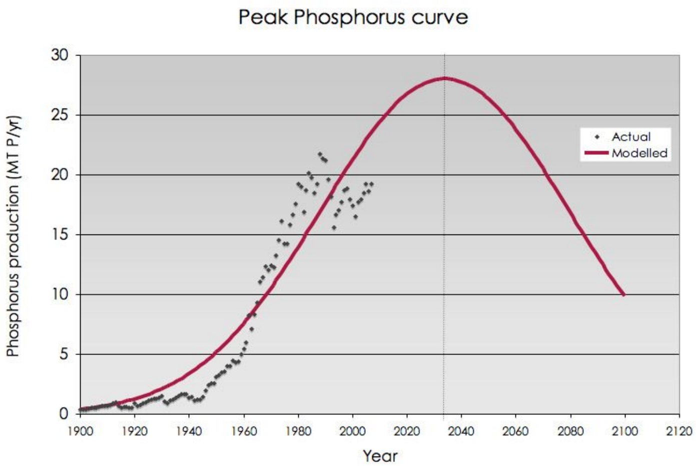
### *7.1.2 Phosphorus*

Phosphorus is the other major non-renewable resource where scarcity could significantly affect crop yields by 2050.[20] Recent work by Cordell *et al.* (2009) estimates peak production of phosphates by 2034, using the Hubbert curve which predicts declining production of oil and other mineral resources when half of reserves have been exploited (Figure 7.2). Production will also become more concentrated especially in Morocco as the United States of America has only 20-25 years of reserves remaining, and China has a high export tax. The quality of deposits is also declining, raising the cost of extraction of remaining reserves.

However, as with N, there is much room to enhance efficiency of P use. Of the 14.9 Mt P mined for agriculture only 6.1 Mt of P is removed in crop biomass. On-farm efficiency can be improved through application of many of the same site specific management practices as for N, though the big difference here is that N is a mobile element that can be leached, while P remains in the soil, slowly building up (in advanced agriculture more P is applied than removed in biomass) in forms which are less available to most plants; microbial additives and genetic engineering of crop roots may improve the accessibility of these unavailable forms of soil P. It is also likely that increased recovery of P from human and animal excreta for use as fertilizer will become common as the technology for recycling is developed and prices of P rise (Cordell *et al.*, 2009).

[20] World reserves of potash appear to be sufficient to provide sufficient supplies well beyond 2050, but are concentrated in few locations – 96 percent is produced in North America, Europe and the Middle East (Dobermann, 2007).

**Figure 7.2: Projection of Peak Global Phosphorus Extraction**




Source: Cordell, Drangert and White (2009)

### 7.2 The Production efficiency gap

Many areas could produce the same or higher yields with lower input costs through practices designed to enhance input efficiency. Over the past two decades, economists have carried out hundreds of studies to estimate farm level efficiency in relation to the production frontier reached by the best farmers. A meta-analysis of 167 such studies concluded that average technical efficiency is 72 percent with a high of 82 percent for Western Europe and a low of 70 percent for Eastern Europe (Bravo-Ureta *et al*., 2007).

While most of these studies fail to adequately account for site and season characteristics specific to plots and farms, they find efficiency is most closely related to farmer characteristics, especially education, location, and access to information (Ali and Byerlee, 1991). A further finding is that education has a significant impact on productivity in most post Green Revolution settings where management is increasingly knowledge intensive.

Information and communication technologies (ICT) in what is often termed ‘precision agriculture’ have much potential to enhance productivity as well as to contribute to more sustainable production systems. These new tools such as yield mapping, leaf testing to time N application, remote sensing, crop modeling and expert systems, improved weather forecasting, and wireless in-field monitoring, aim to improve input use efficiency by allowing inputs to be more precisely calibrated to within-field variability and seasonal conditions (Sudduth, 2007). In small farm agriculture these techniques are also being applied. The leaf color chart is being used by very small farmers to time N application on rice (Islam *et al.*, 2007). And with the spread of mobile phones and village information kiosks, farmers can increasingly tap external sources of information on prices and crop management as well as identify pests and diseases remotely.

However, this type of “precision farming” will require greatly improved knowledge transfer systems, additional equipment, and skilled and educated farmers to achieve its full potential. To date, the potential of this information technology revolution has received too little attention relative to the biotechnology revolution.

### 7.3 Agricultural price policies

Price policies can also be important to achieving high yields and efficiency. Historically, developing countries have heavily taxed their agricultural sectors in part to provide cheap food, penalizing overall rates of growth of the sector. This situation has largely been resolved under liberalization policies of the 1990s, and the average tax on agriculture is now low (Anderson, 2009). This has provided a one-off opportunity to spur productivity growth which will not be available in the future. However, yields of food crops are generally quite inelastic with respect to prices, at least in the short term (Binswanger, 1989; Rosegrant *et al.*, 2008). Progress in dismantling price distortions has been much slower in industrial countries where farm subsidy programs have favored a few crops and discriminated against adoption of more sustainable cropping systems, especially crop rotations.

Subsidies on many inputs and outmoded pricing structures for inputs, especially water, are still common in Asia. These policies played a role in stimulating adoption of Green Revolution inputs in the 1970s and 1980s, but given current high levels of input use, they undermine incentives to use inputs more efficiently. Supporting institutional reforms will also be important—for example, the greater devolution of water management decisions to users, and a gradual shift to market-determined water allocation systems.

In Africa where yields and input use are still very low, there is a case for 'market smart' input subsidies to promote adoption of fertilizers and stimulate input market development. Several countries have re-introduced such subsidies (World Bank, 2007). However, high fiscal costs and displacement of commercial sales threaten their long-run sustainability and effectiveness.

### 7.4 Prospects for TFP growth

Finally, what does all of this mean for TFP growth? In general, TFP growth accounts for a higher share of agricultural output growth as agricultural economies develop (Pingali and Heisey, 1999). TFP growth was responsible for half of output growth after 1960 in China and India, and 30–40 percent of the increased output in Indonesia and Thailand (World Bank, 2007). There is little evidence that growth in TFP is slowing (Box 7.1).

TFP growth is largely explained by investments in research, extension, education, irrigation, and roads as well as policy and institutional changes (Pingali and Heisey, 1999; Binswanger, 1989; World Bank, 2007; Kumar, 2008). Decompositions of productivity gains consistently point to investment in research often associated with extension as the most important source of growth. Improved varieties alone contributed as much as half of total factor productivity gains in Pakistan and China in the post Green Revolution period (Rozelle at al., 2003; Ali and Byerlee, 2002). Even in Sub-Saharan Africa, the impact of R&D has been identified as important in its (limited) productivity growth (Lusigi and Thirtle, 1997).

**Box 7.1: Is TFP Growth Slowing?**

Recent work by Fuglie (2008) provides an up to date and comprehensive overview of TFP growth (Table 7.3). While these estimates are for all agriculture and not just for cereals, the general conclusion is that TFP growth has accelerated in the most recent period since the Green Revolution, 1991-06, in spite of slower output growth. Input growth has slowed in all regions, and in developed countries is now negative. This is especially so in the former Soviet block, where inputs were used very inefficiently before the transition to markets.

In developing countries, total output growth has not slowed, implying that growth from diversification to higher value products has canceled slower growth in cereals. High growth in both output and TFP is led by large countries, especially Brazil and China, with TFP growth above 3 percent/year. Nonetheless, Fuglie (2008) recognizes that cereal growth has slowed significantly and that TFP for individual commodity groups may show different patterns. Indeed, a recent review by Kumar *et al*. (2008) suggests some slowing of TFP growth in cereals in South Asia, with negative growth in rice in the Punjab. This supports earlier evidence of slowing TFP growth in rice-wheat systems in India and Pakistan (Murgai *et al*., 2001).

Overall, the share of growth accounted for by TFP has risen from one third in the period 1970-90 to nearly two thirds in the period, 1991-2006 in developing countries. In line with the earlier analysis, sub-Saharan Africa is the outlier with growth dependent on land expansion rather than TFP—in fact, land area has expanded more rapidly than output, although there is evidence of recent acceleration of productivity growth in some countries such as Ghana (Fuglie, 2009).

**Table 7.3: Growth of total output, inputs and total factor productivity (TFP) in agriculture**

| | **Output** | | **Input** | | **TFP** | |
|---|---|---|---|---|---|---|
| **Region** | 1970-90 | 1991-06 | 1970-90 | 1991-06 | 1970-90 | 1991-06 |
| | (%/yr) | (%/yr) | (%/yr) | (%/yr) | (%/yr) | (%/yr) |
| sub-Saharan Africa | 2.03 | 2.67 | 1.72 | 1.81 | 0.31 | 0.86 |
| Latin America | 2.69 | 3.03 | 1.68 | 0.59 | 1.02 | 2.44 |
| Asia | 3.36 | 3.57 | 1.85 | 0.95 | 1.51 | 2.62 |
| MENA | 3.15 | 2.54 | 2.02 | 1.01 | 1.14 | 1.53 |
| North America | 1.49 | 1.61 | 0.00 | -0.30 | 1.49 | 1.91 |
| Europe | 1.10 | -0.15 | -0.16 | -1.66 | 1.26 | 1.52 |
| Russia, Ukraine and Central Asia | 0.99 | -1.57 | 1.17 | -3.95 | -0.17 | 2.38 |
| | | | | | | |
| Developed Countries | 1.35 | 0.87 | -0.27 | -1.18 | 1.61 | 2.05 |
| Transitional countries[a] | 0.95 | -1.48 | 0.94 | -3.28 | 0.00 | 1.79 |
| Developing Countries | 3.16 | 3.41 | 2.08 | 1.22 | 1.08 | 2.19 |
| | | | | | | |
| World | 2.16 | 2.13 | 1.37 | 0.57 | 0.79 | 1.56 |

[a] Countries of the former Soviet Union

Source: Fuglie (pers comm), recalculated from Fuglie (2008)

## 7.5 The key role of R&D investments

The question is what level of investment in R&D will be needed to realize needed gains in yields and productivity to secure global food security to 2050. von Braun *et al.* (2008) estimate that a doubling of investment in R&D in developing countries would increase the contribution of R&D to overall output growth by 1.1 percentage points (i.e. approximate doubling of current rates), sufficient to assure a continued decline in poverty (and presumably food prices) through 2020. This scenario appears to be quite similar to the high R&D investment scenario of Rosegrant *et al.* (2008) that reverses an upward trend in real prices of grain to 2050 relative to the baseline. However, there is a wide margin of uncertainty in estimates of the quantitative relationship between R&D investments and yield and productivity growth, especially the time lags involved, even though ex-post analyses of research impact have invariably yielded very attractive rates of return.

These scenarios do not consider investment in R&D in industrial countries which will continue to play a major role in global food security as developing countries urbanize and likely increase their dependence on food imports. Spillovers from R&D in industrial countries are also important to developing countries. Combined public and private agricultural R&D investment in industrial countries is double that in developing countries. There are worrying signs of reduced public investment in R&D in industrial countries as well as reallocation to non-productivity issues such as food safety and the environment could reduce resources for long term strategic research of relevance to developing countries, such as efforts to push out the yield frontier (Pardey *et al.*, 2007). Meanwhile, private investment in R&D has increased rapidly in industrial countries. A conservative estimate is that the private sector spends about $1 billion annually on maize research in the United States of America, compared with $181 million in 1990 in 2008 dollars (Byerlee and Lopez, 1994). This huge increase is a likely explanation for the continuing impressive yield gains in maize in the United States of America, and in like environments where these companies and their subsidiaries operate.

Nonetheless, there are worries about the sustainability of recent trends in private R&D spending, which has been increasing exponentially while yields have been increasing linearly (Duvick and Cassman, 1999). The large jump in private spending may have finally driven returns to investment in R&D down from their very high levels of over 50 percent to rates closer to a risk-adjusted cost of capital. If so, the era of rapid growth in private investment in maize and soybean research may be over, although the spread of hybrid rice could result in a similar burst of investment in that crop. Unpublished data from the United States Department of Agriculture indicate a leveling of private spending in the United States of America from 2000. One factor that may trigger a new round of private investment in food crops would be if transgenics become accepted by the public for major food staples such as rice and wheat.

Finally, it is likely that over the long term, productivity-enhancing investments are driven by prices. There is evidence that public investment in rice research and irrigation in Asia was negatively affected by the long-term fall in real rice prices (Hayami and Morooka, 1987; Rosegrant and Pingali, 1994). Private research is likely to be even more responsive to prices and the recent increases in food prices may have already led to a resurgence of R&D spending. Thus over the long term, yields may be much more elastic with respect to prices than they are in the short to medium term.

# 8. CONCLUSIONS

It is common that when world grain prices spike as in 2008, a small fraternity of world food watchers raises the Malthusian specter of a world running out of food. Originally premised on satiating the demon of an exploding population, the demon has evolved to include the livestock revolution, and most recently biofuels. Yet since the 1960s, the global application of science to food production has maintained a strong track record of staying ahead of these demands. Even so, looking to 2050 new demons on the supply side such as water and land scarcity and climate change raise voices that "this time it is different!" But after reviewing what is happening in the breadbaskets of the world and what is in the technology pipeline, we remain cautiously optimistic about the ability of world to feed itself to 2050, as was L.T. Evans at the end of his long excursion through these same issues (Evans, 1998).

First, despite impressive gains in yields over the past 50 years in most of the world, large and economically exploitable yield gaps remain in many places, especially in the developing world and nowhere more so than in sub-Saharan Africa where food supply is the most precarious.

Second, in the short to medium term, there are many technologies that are in their early stage of adoption that promise a win-win combination of enhancing productivity and sustainably managing natural resources. These include conservation farming approaches based on no tillage and the GM technology revolution—both still only used on less than 10 percent of the world's cropland—as well as the even earlier adoption phase of information and communication technologies (ICT) for more efficient and precise management of modern inputs.

Third, yield gains are not achieved by technology alone, but also require complementary changes in policies and institutions. In much of the developing world, policies are now more favorable for rapid productivity growth, while a range of innovations in risk management, market development, rural finance, organizing farmers, and provision of advisory services, show considerable promise to make markets work better and provide a conducive environment for technology adoption. Indeed, in sub-Saharan Africa these innovations are a necessary condition for wider adoption of critical technologies such as fertilizer.

Fourth, plant breeders continue to make steady gains in potential yield and water-limited potential yield, more slowly than in the past for wheat and rice, but with little slackening in the case of maize; there is no physiological reason why these gains cannot be maintained but progress is becoming more difficult with conventional breeding. Genomics and molecular techniques are now being regularly applied to speed the breeding in the leading multinational seed companies and elsewhere, and their costs are falling rapidly. As well, transgenic (GM) technology has a proven record of over a decade of safe and environmentally sound use and its potential to address critical biotic and abiotic stresses of the developing world, with positive consequences for closing the yield gap, has yet to be tapped. We believe that the next seven to ten years will see its application to major food crops in Asia and Africa and that after its initial adoption, the currently high regulatory costs will begin to fall. We note however that this will require significant additional investment, not least in the areas of phenotyping on a large scale, and that it still takes 10-15 years from the initial investment until resulting technologies begin to have major impact on food supply. Transgenics for greater water-limited potential yield may also appear by then, but trangenics for greater potential yield, arising from significant improvements in photosynthesis, may take longer than even our 2050 horizon.

To be sure these are broad generalizations and there are important differences by crop and region. This review of the big three cereals has shown that maize is the dynamic crop, with no evidence of slowing yields and with huge potential in the developing world. It is also the crop experiencing the most rapid increase in demand, largely for feed and fuel, and the crop attracting the largest R&D research budget. Wheat demand and yield growth appear to be intermediate, the latter perhaps because of disease resistance and industrial quality constraints on breeding, as well as the bigger role of water stress in its production environment. Yield gains in rice are more problematic, but demand growth is also less, although it is a particularly important food staple for the poor of Asia, where rice area is shrinking, and increasingly Africa. And although increases in food production in Asia over the past 50 years have been impressive, no country in sub-Saharan Africa has yet experienced a green revolution in food crops in a sustained manner, despite generally better overall performance of the agricultural sector in the past decade.

Yet our review does raise a number of cautions. First, we have not (yet) reviewed other food crops—sorghum and millet, roots and tubers, pulses and oilseeds. Many of these crops are not globally important, but are critical to local food security, cassava in Africa for example. Others are growing commercial crops for an urbanizing population—potatoes for fast foods, and oilseeds for feed.

Second, the future of biofuels is the new wild card in the world food economy. To no small extent the need to accelerate global cereal yield trends beyond the historic annual rate of 43 kg/ha for 1961-2007 relates to this new demand. By 2020, the industrial world could consume as much grain per capita in their vehicles as the developing world consumes per capita directly for food.

Third, many countries face huge challenges in achieving food security, even from a narrow perspective of food supply. We are less concerned about China and India, since they should continue to be largely self sufficient for food needs (although depending on imports for part of their feed needs), but much depends on investments in R&D (below) and management of natural resources. However, there are many countries that do not have the capacity to import large amounts of grain or it would be prohibitively costly to do so, but where population growth is still very high. Most of these are in Africa, but even Pakistan with an estimated 335 m people in 2050 faces a potential food crisis. Climate change will also be a major challenge for many of these countries, adversely affecting yields and diverting R&D resources toward adaptation rather than yield improvement - adding a new dimension to maintenance research.

Finally, past agricultural success has in a sense been achieved by mining of non-renewable resources - fossil energy, phosphate, and much underground water. Our review of the impact of looming limitations of this strategy raises major concerns. This places a premium on improved efficiency of using these resources that must be at the center of the agenda for Feeding the World in 2050. Generally it should be noted that increased yield through breeding and agronomy is lifting resource use efficiency.

The history of agriculture in the twentieth century teaches us that investment in R&D will be the most important determinant of whether our cautious optimism will be realized. We see indications that major developing countries such as China, India and Brazil are poised to close the gap in research intensity with the industrial countries. The CGIAR is also revamping its efforts, aiming to double its budget in the coming years. However, there are many technological orphans that are falling behind in R&D spending (Beintema and Howard, this conference). The private sector too, must be encouraged to make a big impact beyond its mainstays of maize and soybeans, especially in rice. But innovative partnerships will be needed to access and adapt technologies to the world's 800 million small farmers.

Resilience, flexibility and policies that favor R&D investment in staple food research and efficient input use will be the pillars upon which future food security depends. Darwin, whose 200$^{th}$ birthday we celebrated this year leaves two relevant statements: "If the misery of the poor be caused not by the laws of nature, but by our institutions, great is our sin," and, "It is not the strongest of the species that survives….[but]…. the one that is the most adaptable to change."

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# SETTING MEANINGFUL INVESTMENT TARGETS IN AGRICULTURAL RESEARCH AND DEVELOPMENT:
## CHALLENGES, OPPORTUNITIES AND FISCAL REALITIES[1]

**Nienke Beintema and Howard Elliott**[2]

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[1] Paper prepared for the Expert Meeting on "How to Feed the World in 2050". FAO, Rome. June 24-26, 2009. The views expressed in this information product are those of the author(s) and do not necessarily reflect the views of the Food and Agriculture Organization of the United Nations.

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## EXECUTIVE SUMMARY

1. The rate of growth in agricultural research and development (R&D) investment has been declining globally while a large number of developing countries have experienced negative growth rates over the past decade. Stagnating investment in sub-Saharan African agricultural research is particularly worrisome. General underinvestment is evidenced by: 1) the continuing high rates of return to research demonstrated in studies at the commodity level; and 2) by macroeconomic studies showing that the relevant Millennium Development Goals (MDGs) cannot be reached without a doubling or even tripling of research investment given estimated growth-poverty-reduction elasticities, Also of concern is new evidence that a change in the composition of research away from productivity-enhancement at the farm level is statistically related to a decline in the growth of agricultural productivity in advanced economies below historical levels. This trend may be considered another form of underinvestment that reduces potential spillovers in the future. Policy makers are reminded that growth in agricultural productivity provides the consumption, savings and taxes needed for development and attainment of social goals.

2. Capacity in agricultural research is increasingly concentrated in a few leading countries in each region. While efforts are underway to create new structures or mechanisms for collaboration across the global, regional and national levels, policy makers are reminded that no country is too poor or too small to support a national effort that is "sufficient" to gain from global knowledge. Various investment targets have been adopted over the years such as CAADP's "public expenditure on agriculture equal to 10 percent of the national budget. " Seen from the results side, investment should be sufficient to produce 6 percent growth in agricultural production (or to meet MDG1). Such targets do not provide guidance on the feasibility of the target and how fast one can build up the institutional and human capacity to achieve them.

3. One of the main indicators to compare relative R&D investment levels, is the ratio of agricultural research investment over agricultural output, the so-called "agricultural research intensity ratio (ARI)". An ARI of 1 percent has been seen by many as a target that low income agriculturally-based countries should strive for. However, the ARI by itself is influenced by several factors that need to be studied in depth at the country level. The ARI can be decomposed into an identity with four components: 1) priority to research within agricultural expenditure; 2) priority to agriculture in total public expenditure; 3) fiscal capacity measured as the ratio of public expenditure to gross domestic product (GDP) and 4) the (inverse of the) share of agriculture in the GDP. Analysis of each of these elements in a country's effort highlights the importance of strategy and priorities; the institutions and incentives; public sector finance and public expenditure management; and the role of global partners.

4. Emerging challenges, such as adaptation to climate change and increasing variability of weather, water scarcity, and increased price volatility in global markets will be faced by many countries that are least able to adapt to existing stresses. This lends increasing importance to developing the human and institutional capacity in agricultural research at the national level to interact with regional and global efforts underway. A systemic approach to planning will bring universities and research institutes closer together.

## SECTION 1 INTRODUCTION

This paper is ultimately aimed at policymakers who ask "Is there enough investment in agricultural research and development (R&D)?" They are constantly being reminded by declarations made, commitments signed and targets held up that assert that they must do more or better. In order to provide some analytical structure and limits to the discussion, we look at "underinvestment" separately from the demand and the supply sides and then at the investments, policy actions and institutional arrangements that are needed to bring supply and demand into balance.

This paper has four sections in addition to this introduction. Section 2 sets the scene by providing historical trends in human and financial investments in agricultural research and development (R&D). Section 3 looks at "underinvestment" in three ways (two technical and one political). First, evidence of a continuing high rate of return relative to the social rate of discount is a formal definition of "underinvestment" since additional investment would add more to social gains than to social costs. Second, failure to maintain on-farm productivity growth at its historical trend and potential contribution is a sign of underinvestment. Finally, if there are large gaps between the resources required to attain political commitments, e.g. the Millennium Development Goals (MDGs) with respect to poverty and hunger; there is underinvestment with respect to political commitments. We do not say anything at this point about how fast the gaps must be eliminated if we want to avoid waste.

Turning to the "supply side" in Section 4, we pose the question whether a country's national effort is commensurate with its financial and human resource capacities to permit it to "do more" to deliver on commitments to investment targets set in various international fora. On the finance side, we go into several public finance issues on the taxation and expenditure sides (which are not independent of each other). We create an identity out of the agricultural research intensity ratio, analyze the four components that determine its value, and comment on what might be done to increase investment in R&D. On the human resource side, we identify gaps in both research and higher education that affect the ability of research institutions to ramp up their effort in response to emerging challenges. The financial resource needs cut across the global to local scales.

Section 5 deals with new challenges imply not just reinvestment in agricultural R&D but also necessary investment in other parts of the knowledge system for balanced growth. A demand for more highly trained researchers to deal with climate change, price volatility in global markets, or water scarcity is a demand on the university system to expand MSc and PhD training. The expanded cadre provides valuable research support to existing scientists while learning the advanced skills needed to become senior researchers.

New challenges bring with them new approaches, demands for new skills and new institutional arrangements for collaborative research. The time and process by which these new arrangements come about are necessary investments.

## SECTION 2: TRENDS IN AGRICULTURAL R&D INVESTMENTS[3]

### 2.1 Public agricultural R&D spending

Global public agricultural R&D investment (including government, nonprofit, and higher education sectors) totaled $23 billion in 2005 PPP dollars in 2000, the latest year for which comparable global data are available.[4]

[3] This section draws on Beintema and Stads ( 2006, 2008a+b), Stads and Beintema (2009), and underlying datasets of the Agricultural Science and Technology Indicators (ASTI) initiative (www.asti.cgiar).

[4] Financial data in this paper are reported in real values using gross domestic product (GDP) deflators using the benchmark year 2005 and purchasing power parity (PPP) indexes taken from the World Bank (2008a). PPPs are synthetic exchange rates used to reflect the purchasing power of currencies, typically comparing prices among a broader range of goods and services than conventional exchange rates. These global trends differ from those reported in Pardey et al. (2006). These revisions were in response to World Bank adjustments to its comparative pricing of goods and services across countries (using PPP indexes), reclassification of non-OECD high-income countries, and new estimates for Latin America and a number of other countries (Beintema and Stads 2008a).

Total public investment increased considerably from the $16 billion reported in 1981 (Table 1). But this increase did not take place equally across all regions in the world. Spending in the Asia-Pacific region more than doubled during the two-decade period or, measuring in growth rates, increased at 4.2 percent per year (Figure 1).[5] This was largely a result of high growth in agricultural R&D spending in the two largest countries, China and India (annually 4.4 percent and 5.8 percent, respectively). In contrast, spending in sub-Saharan Africa only grew, on average, by 0.6 percent per year during 1981-2000. More worrisome is that the spending for the region as a whole contracted slightly during the 1990s with more than half of the sub-Saharan African countries for which time series data were available spending less in 2000 than they did in 1991.

As a result of these different regional growth patterns, the distribution of agricultural R&D spending changed during the two decade period. Due to the high increase in total spending in the Asia-Pacific region, its share in the global total increased from 12 percent in 1981 to 20 percent in 2000. As a result the shares of sub-Saharan Africa and Latin America declined during the 20-year period to 5 percent and 12 percent of the total, respectively. Interestingly is that the total public agricultural R&D spending in sub-Saharan Africa as a whole was lower than total spending in Brazil, the largest public investor in Latin-America, and considerably lower than the spending levels in India and China. Although spending in high-income countries as a whole continued to grow in absolute terms, their share of total global spending declined from 62 percent to 57 percent. The share of spending by low and middle income countries increased from 9 percent to 11 percent and 29 percent to 32 percent, respectively.

**Table 1: Total public agricultural R&D expenditures by income class and region, 1981, 1991, and 2000**

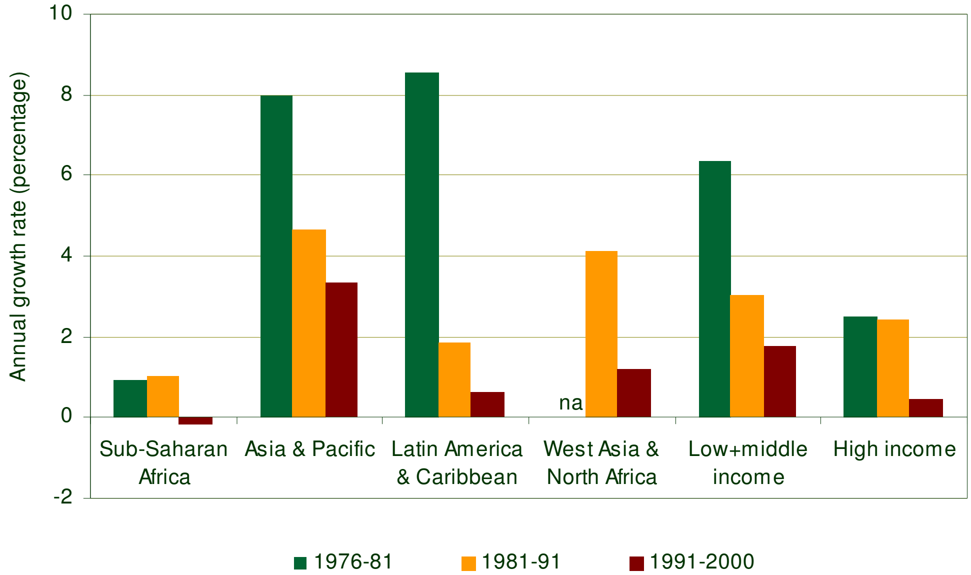
| Country category | Public agricultural R&D spending | | | Regional share of global total | | |
|---|---|---|---|---|---|---|
| | 1981 | 1991 | 2000 | 1981 | 1991 | 2000 |
| | (*million 2005 PPP dollars*) | | | (*percent*) | | |
| **Country grouping by income class** | | | | | | |
| Low income (46) | 1,410 | 2,009 | 2,564 | 9 | 10 | 11 |
| Middle income (62) | 4,639 | 6,301 | 7,555 | 29 | 30 | 32 |
| High income (32) | 9,774 | 12,577 | 13,313 | 62 | 60 | 57 |
| ***Total (140)*** | ***15,823*** | ***20,887*** | ***23,432*** | ***100*** | ***100*** | ***100*** |
| **Low- and middle-income countries by region** | | | | | | |
| Sub-Saharan Africa (45) | 1,084 | 1,253 | 1,239 | 7 | 6 | 5 |
| China | 713 | 1,178 | 1,891 | 5 | 6 | 8 |
| India | 400 | 748 | 1,301 | 3 | 4 | 6 |
| Asia–Pacific (26) | 1,971 | 3,287 | 4,758 | 12 | 16 | 20 |
| Brazil | 1,005 | 1,433 | 1,209 | 6 | 7 | 5 |
| Latin America and the Caribbean (25) | 2,274 | 2,697 | 2,710 | 14 | 13 | 12 |
| West Asia and North Africa (12) | 720 | 1,074 | 1,412 | 5 | 5 | 6 |
| ***Subtotal (108)*** | ***6,049*** | ***8,310*** | ***10,119*** | ***38*** | ***40*** | ***43*** |

Sources: Beintema and Stads (2008a) based on ASTI datasets (www.asti.cgiar.org) and other secondary sources.

Notes: The number of countries included in the regional totals is shown in parentheses. These estimates exclude Eastern Europe and former Soviet Union countries. Estimation procedures and methodology are described in Pardey et al. (2006) and various ASTI regional reports available at www.asti.cgiar.org.

[5] The regional totals refer to developing countries (defined as low and middle income countries) only and exclude high income countries such as South Korea in the Asia-Pacific region and Israel and Kuwait in the Middle East and North Africa region.

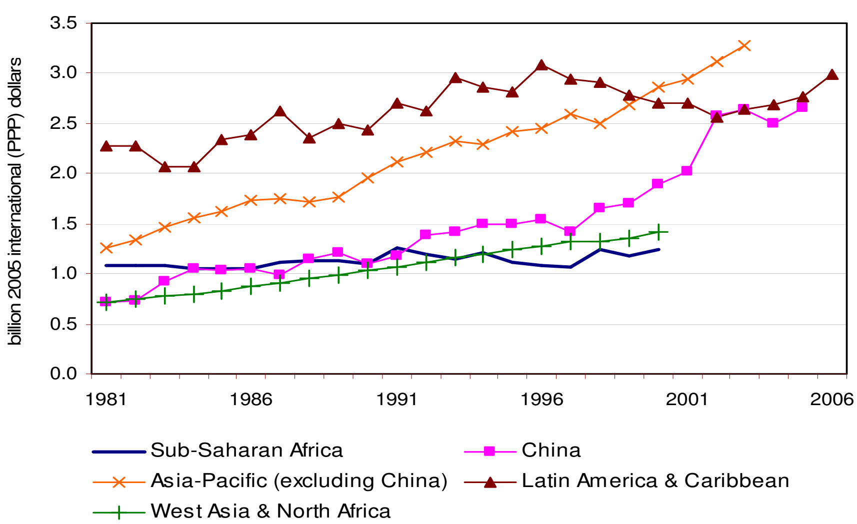
**Figure 1: Annual growth rates in agricultural R&D spending, 1976-2000**




Sources and Notes: See Table 1.

Although data on global public agricultural R&D investments patters since 2000 are still unavailable,[6] more recent data collected by the Agricultural Science and Technology Indicators (ASTI) initiative show that investments continued to grow in China and India (Figure 2). Agricultural R&D expenditures in Latin America and the Caribbean rebounded in recent years following a period of contraction during the late-1990s, which was mostly due to financial crisis in a number of Southern Cone countries. No recent investment data are yet available for sub-Saharan Africa, but new information collected by the ASTI initiative in 14 countries indicate that the overall research capacity, in terms of the number of full-time equivalent (FTE) researchers has increased for many countries since 2000 (Beintema and Di Marcantonio 2009). Although this is useful information, it cannot be used as proxy for the direction of investment trends within the region.

**Figure 2—Public agricultural R&D investment trends in developing countries, 1981-2006**



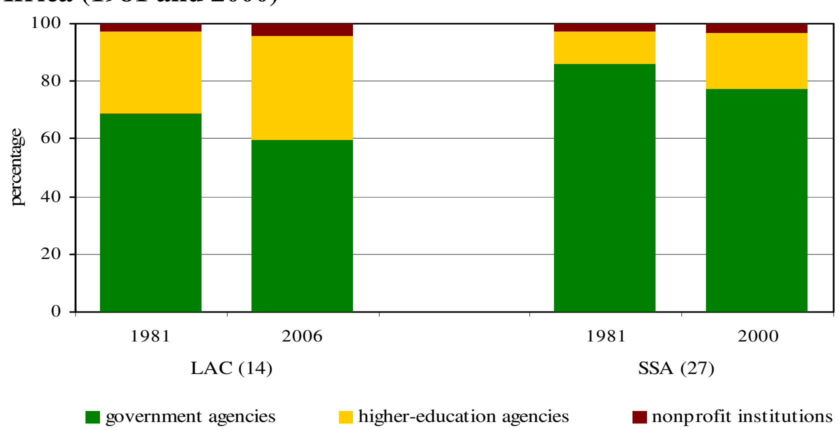

Sources: ASTI datasets and secondary sources underlying Beintema and Stads (2008a+b) and Stads and Beintema (2009).

[6] Data collection efforts by the ASTI initiative are underway in sub-Saharan Africa and will be expanded to a number of other low- and middle-income countries to ensure a new global update for the year 2009.

Public agricultural R&D, however, has become increasingly concentrated in just a handful of countries (Pardey et al. 2006). The top five countries in terms of agricultural R&D spending, the United States, Japan, China, India, and Brazil, spent 48 percent of total global public agricultural R&D; from 41 percent in 1991. Meanwhile, only 6 percent of the agricultural R&D investments worldwide were conducted in 80 (mostly low-income) countries that combined had a total of more than 600 million people and accounted for 14 percent of the world's agricultural land area. In Latin America about three-quarters of the total public investments in agricultural R&D were spent by only three countries, Brazil, Mexico, and Argentina. Since the mid-1990s the investment gap has widened between the region's low and middle income countries, which in part was the result of sharp cuts in research expenditures in some of the poorer, more agriculture-dependent countries such as Guatemala and El Salvador. Similarly in Asia, although less pronounced, a knowledge divide between the region's rich and poor countries and the scientific "haves" and "have-nots" is becoming more and more visible. During the period 1981–2002, especially in the latter decade of the period, both China and India intensified their agricultural research spending while other smaller countries, such as Malaysia and Vietnam, also realized impressive agricultural R&D spending growth. But other countries such as Pakistan, Indonesia, and Laos, proved sluggish and at times negative, largely due to the Asian financial crisis, the completion of large donor-financed projects, or high rates of inflation. In Africa agricultural research has been historically better funded in some countries such as Kenya and South Africa compared to a large number of the very poorest countries in the region, specifically in Western Africa. But there is no evidence that this divide has increased over the past few decades; this in part because of the donor dependency of many countries as well as the erratic nature of government and donor support to agricultural research over the years.

The government sector is still the main player in public agricultural R&D, in terms of execution as well as funding. The government sector accounted for 60 percent and 77 percent of total FTE staff in Latin America (data for the year 2006) and Sub-Saharan Africa (data for the year 2000/1), respectively (Figure 3). Despite this leading role of the government sector, the higher-education sector has gained prominence and quite a number of countries. It accounted for 36 percent of total public agricultural R&D in Latin America compared to 29 percent in 1981. The higher-education shares in sub-Saharan Africa increased from 11 percent in 1981 to 19 percent in 2000. In absolute terms, the total number of FTE researchers employed in the higher education sector almost doubled in Latin America and tripled in Sub-Saharan Africa. In a number of countries (e.g., Argentina and Mexico), the research capacity in higher education approaches that found in the government sector. In India the higher education sector has surpasses the government sector in terms of FTE agricultural research staff. The latter is the result of the integration of research, extension, and education in the India system. Despite the increasing share of the higher-education sector as a whole, the individual capacity of each faculty/school remains often very small and the agricultural higher-education system fragmented (e.g., Sudan, Philippines, and Nigeria).

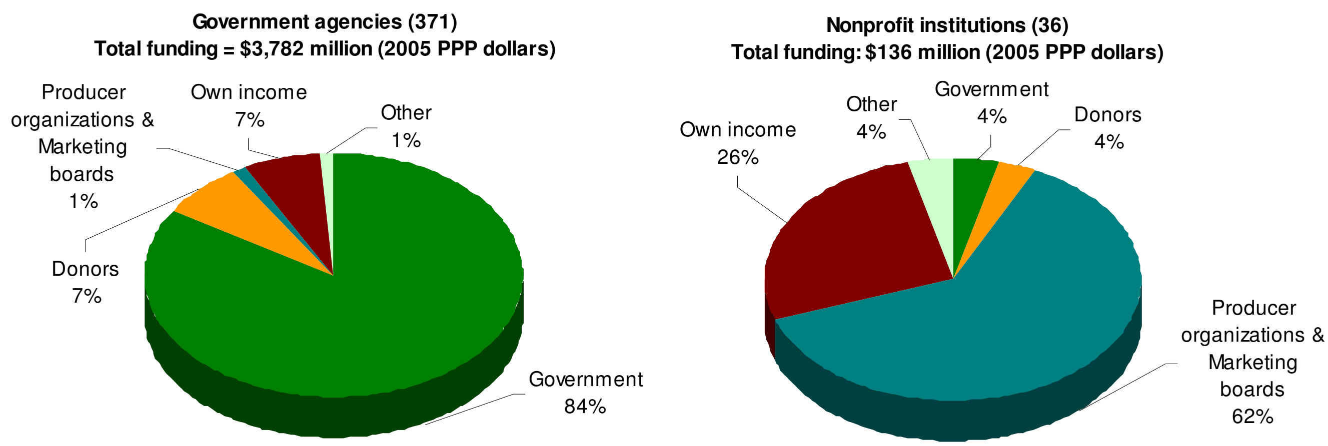
**Figure 3: The institutional orientation of agricultural research in LAC (1981 and 2006) and sub-Saharan Africa (1981 and 2000)**




Source: ASTI datasets underlying Beintema and Stads (2004) and Stads and Beintema (2009).
Note: Shares are measured in terms of full-time equivalent (FTE) researchers. The number of countries is indicated in parenthesis

The government sector is also still the largest contributor to public agricultural research (Figure 4). Government allocations accounted for an average of 81 percent of total funding received by a sample of more than 400 government agencies and nonprofit institutions in 53 developing countries. Only 7 percent of total funding was received from donor contributions, in the form of loans or grants. This share was mostly driven by the high donor dependency of government agencies in sub-Saharan Africa. For the main government agencies in 23 countries for which data were available, 35 percent of their funding came from donor loans and grants in 2000/1. Funding generated through internally generated funds, including contractual arrangements with private and public enterprises, accounted for an average of 7 percent of total funding. The 36 nonprofit organizations in the sample received close to two-thirds of their funding contributions from producer organizations and marketing boards. These contributions were mostly collected through taxes raised on export or production of commercial crops. The nonprofit organizations were also more active than the government agencies to raise income from internally generated resources, which included contract with private and public enterprises (26 percent).

**Figure 4—Composition of funding sources for various years since 2000**



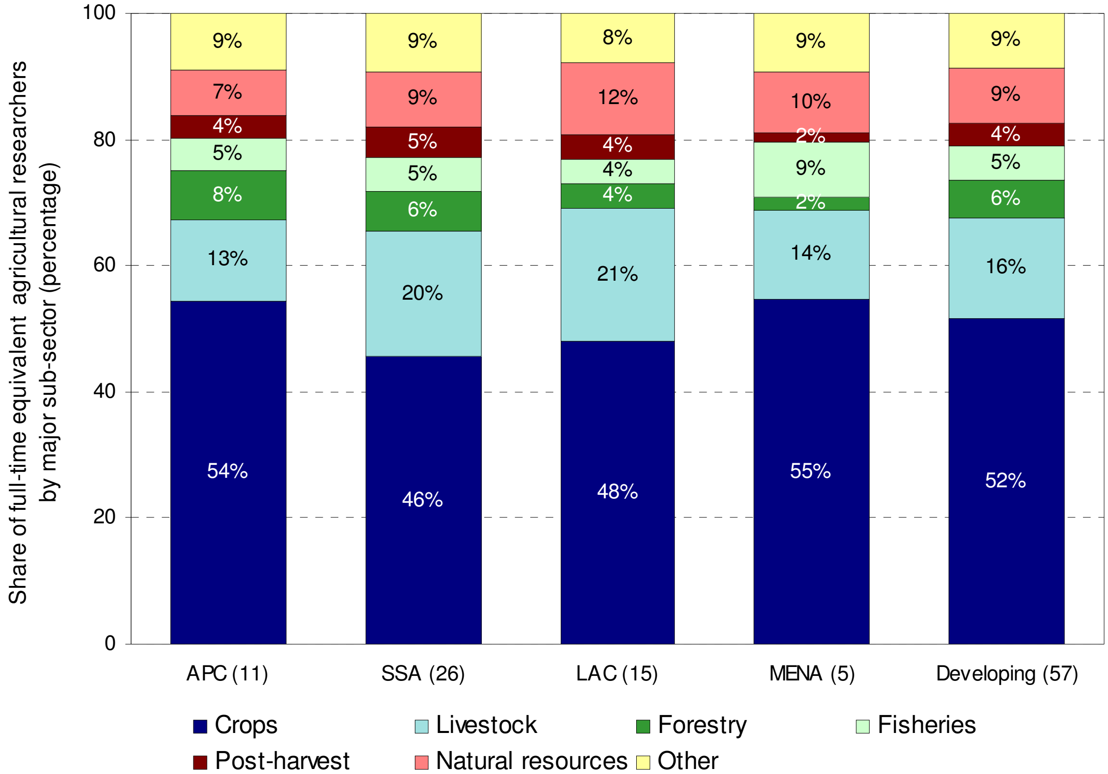

Source: ASTI datasets underlying Echeverria and Beintema (2009).

Note: Own income includes contracts with private and public enterprises. Data is for 53 developing countries but exclude China, Nigeria, and South Africa; large countries in terms of agricultural R&D investments.

Although government allocations still present the main source of funding, there are again considerable differences across countries. A number of developing countries depend on non-governmental sources of funding. In Africa this is the result of high donor dependency. A number of countries in Africa and other regions, however, have increased the diversity of their funding sources and include considerable income from sale of products or services, contractual arrangements with public and private enterprises, or contributions from producer organizations through taxation of exports or production.

More than one half of the total FTE researchers in agricultural R&D in a sample of 58 developing countries were involved in crops research while 16 percent focused on livestock research (Figure 5). The remaining one third of the researchers focused on forestry (6 percent), fisheries (5 percent), natural resources (9 percent), postharvest (4 percent) and other agricultural disciplines. Researchers in sub-Saharan Africa and Latin America and the Caribbean spent relatively more time on livestock research compared to the overall research staff in Asia-Pacific and Middle East and North Africa regions.

**Figure 5—Research orientation of research staff by main sub-sector**

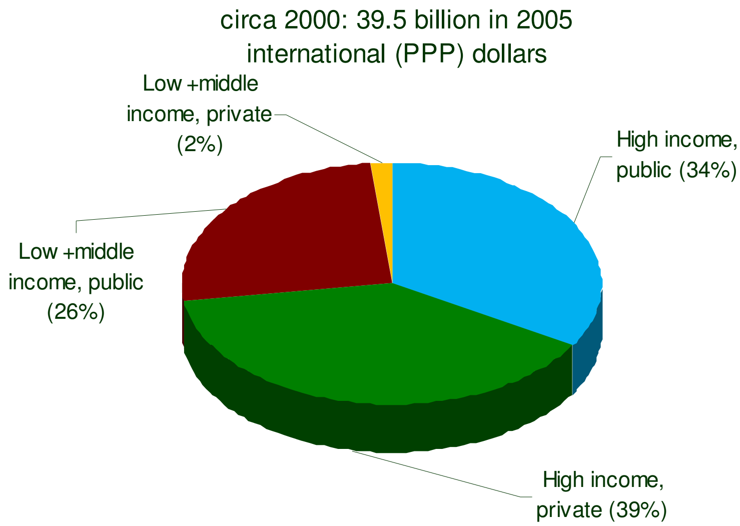



Source: Authors calculations based on ASTI datasets (www.asti.cgiar.org).
Note: The number of countries included in the regional totals is shown in parentheses. SSA stands for sub-Saharan Africa, APC for Asia-Pacific Countries (and excludes here China), LAC for Latin America and the Caribbean, and MENA for Middle East and North Africa. SSA data is for 2000/01, APC for 2002, LAC for 2006, and MENA for 2002/3.

### 2.2 Private agricultural R&D spending

Data on private sector investments in agricultural R&D remain very limited. In 2000, the only year for which global estimates are available, the private sector spent an estimated $16 billion 2005 PPP dollars (Figure 6); 41 percent of global total (public and private). Almost all of these private sector investments were made by private companies performing agricultural R&D in high income countries. Investments by the private sector in the developing world accounted for only 2 percent of the total public and private agricultural R&D investments in 2000; of which most was done by Asian private companies (Beintema and Stads 2008a). The private sector plays a stronger role in terms of funding agricultural research given that many private companies contract research out to government and higher education agencies. But the role of the private sector in most developing countries is and will remain small given the limited funding opportunities and incentives for private research. Furthermore, most private sector research in developing countries focuses on the provision of input technologies or technical services for agricultural production. Most of these technologies are, however produced in the high income countries (Pardey et al 2006).

**Figure 6—Composition of public and private agricultural research investments**




Source: ASTI datasets and secondary sources underlying Beintema and Stads (2008).

There is only limited information on the level of private sector involvement over time or on the type of research private companies are conducting. Alston et al (1999) found that only 12 percent of private research in Australia, the Netherlands, New Zealand, United Kingdom, and United States were focused on farm-oriented technologies in 1992; the corresponding share in the public sector was 80 percent for these countries. Food and other postharvest accounted for 30-90 percent in Australia, the Netherlands, and New Zealand, chemical research between 40-50 percent in the United Kingdom and United States. Pray and Fuglie (2001) found that share of private sector investments in the total agricultural R&D investments had grown during mid-1980s to mid-1990s in China, India, and Indonesia (in a sample of seven Asian countries) and was higher than the growth in public sector investments. But the growth in private sector investments was uneven across subsectors. Investments in the agricultural chemical sector and, in lesser extent, the livestock sector increased substantially while growth was slower in other subsectors such as plantation crops and machinery.

### 2.3 International agricultural R&D investment

The majority of international agricultural R&D is carried out by the 15 research centers of the Consultative Group on International Agricultural Research (CGIAR). The first four centers were established during the late 1950s and the 1960s, with considerable financial support from the Rockefeller and Ford Foundations. During the 1970s, the number of centers increased to 12 and the funding received per center increased over the decade. This led to a tenfold increase (in nominal terms) in the total CGIAR investments. Total funding continued to increase during the 1980s, but at a lower pace. During the 1990s, however, total funding grew less than the increase in the number of centers and spending levels per center could not be maintained. Since 2000, overall funding to the CGIAR has increased, but a larger proportion of this funding is support for specific project and programs of research involving different centers and non-CGIAR research organizations (Beintema et al. 2008; Pardey et al. 2006).

There a number of other international research providers, mostly with a regional or sub-regional focus. For example, the two largest non-CGIAR agencies conducting research in Africa are the French-headquartered International Cooperation and Agricultural Research for Development (CIRAD) and the Institute for Research and Development (IRD). In the Asia region, the Australian Centre for International Agricultural Research (ACIAR) does not conduct research in the region's developing countries itself but develops international agricultural research partnerships. The Japanese International Research Center for Agricultural Sciences (JIRCAS) mandate covers all developing countries; most of its agricultural research is done in Asia. Two important regional agencies that conduct agricultural research in Latin America and the Caribbean are the Agronomic Center for Research and Education (CATIE) and the Caribbean Agricultural Research and Development Institute (CARDI). A number of other international agencies are also active in agricultural R&D in these three regions (Beintema and Stads, 2006, 2008; Stads and Beintema 2009).

## SECTION 3: THERE IS "UNDERINVESTMENT" IN AGRICULTURAL R&D: THREE DEFINITIONS

We argued in the introduction that "underinvestment" in research could be asserted where 1) the rate of return on research was consistently higher than the social rate of return on alternative investments; 2) where the nature of investment had changed so that the country was failing to maintain historical growth in on-farm productivity, and 3) gaps between current investments and the resources really needed to attain pre-set goals.

### 3.1 Evidence from rates of return analysis

The "underinvestment hypothesis" is a straightforward application of marginalist economic theory: if by policy decision or a budget constraint the social value of the last unit of product consumed (or input employed) is greater than the social cost, then there is underconsumption or underuse of the factor because it would pay to borrow until the social gain and social cost are equal. If projects are ranked in descending order by their expected rates of return (call it the marginal efficiency of investment) and the return of the last project undertaken is higher than the social (opportunity cost of capital), this is prima facie evidence of underinvestment.

Hundreds of individual studies of the social rate of return to research consistently show that the rate of return to public investment in agricultural research (40-50 percent) is higher than either the social rate of return on capital or other opportunities for public investment. In general the return to public investment is higher than the private rate of return even after allowing for the marginal excess tax burden of the tax collection system and the returns accrued to farmers. This because it is impossible to appropriate many of the benefits associated to the research done by private firms (Widmer et al 1988; Evenson and Westphal 1995). There is no tendency for the rate of return to decline over time. Furthermore, it appeared that the rates of return may be higher when the research is conducted in more-developed countries (Alston et al 2000).

Roseboom (2002) defines the "underinvestment gap" as the difference between the economic rate of return of the marginal R&D project and the social rate of return. Based on the distribution of projects studied, he concluded that:

> "Under the assumption of full information and rationality, developed countries could have invested about 40 percent more in public agricultural R&D and developing countries about 137 percent more. In terms of agricultural R&D intensity, (i.e. expenditures as a percentage of agricultural GDP developed countries could have invested 2.8 rather than 2.0 percent and developing countries 1.0 percent rather than 0.4 percent in the period 1980-85."

Fuglie and Heisey (2007) analyzed the economic returns of public agricultural R&D in the Unites States and summarized their findings as follows:

- "There appear to be significant social returns to private agricultural research. The private sector is able to capture only a share of the productivity benefits from its technology.
- Agricultural research generates long-term benefits. Public research undertaken today will begin to noticeably influence agricultural research productivity in as little as 2 years and that its impact could be felt for as long as 30 years.
- Agricultural knowledge or research "spillovers" across state and national boundaries are significant."

It is important to note that the rate of return concept measures economic benefits of agricultural investments, but do not measure non-economic impacts such as environmental, social, health, and cultural benefits and costs. These are also important when investment decisions are made, but are not included as they are different to quantify and validate (Beintema et al. 2008). Furthermore, spillovers of agricultural technologies among countries and regions account for a large share of the total social benefits of public agricultural research. When spill-ins occur, rate of returns studies will overestimate the total benefits of the research investment. Similarly, rate of return studies will underestimate the benefits when if spillovers from one country to the other are important (Alston 2002; Beintema et al. 2008). Pardey at al (2006) states that the supply and demand for spillover technologies are changing. Agricultural research in high income countries is increasingly focusing on areas away from the types of technologies that are relevant for the agricultural sector in developing countries (especially the poorest ones). Furthermore, technologies have become less mobile because of stricter intellectual property rights and other regulatory policies.

### 3.2 Failure to maintain historical levels of productivity growth.

It is sometimes necessary to reiterate the importance of productivity. Nobel Prize winner, Sir W. Arthur Lewis (1966) stated unequivocally that "an increase in agricultural productivity is fundamental to the solution of the problem of distribution since it makes possible simultaneous increases in mass consumption, saving and taxation." While agricultural research has proven itself good at increasing on-farm productivity (along with providing spillovers to other social goals); it is a blunt instrument for addressing those other goals directly. Other authors have underlined the importance of productivity growth. Cereal output in developing countries has grown 2.8 percent annually for three decades and yields, not area, were responsible for growth. Total factor productivity has grown along with yields. (Pingali 2009). Today's investment drives tomorrow's growth of productivity (Fuglie and Heisey 2007). Recent studies point out that historical underinvestment in research that is productivity-enhancing at the farm level explains a significant decline in the rate of agricultural productivity growth in developed countries. The greater share of agricultural innovations can be traced to organized, scientific and industrial R&D efforts funded by government and the private sector but this investment has not only slowed down but it has changed it is focused.

Pardey (2009) notes slower productivity growth in the United States in the period 1990-2005 versus growth 1961-89, and suggests several possible causes: bad weather, changing regulatory environment, degradation of natural resource base, slower growth of investment, changing composition of "agricultural research", changing private sector roles and reduced spillovers from other countries and the CGIAR. He argues that this decrease in productivity growth is partly the results of the slowdown in spending and the redirection of agricultural R&D away from maintaining or enhancing productivity.

Alston, Pardey and James (2009) point out that public investments in California agriculture have shown benefit-cost ratios of 10-to-1 indicating substantial underinvestment in agricultural research according to our first definition. In addition to a slowing and increased variability of funding, they add that recent trends indicate that the extent of underinvestment in productivity-enhancing agricultural science may be worsening:

> "Public-sector research has drifted away from on-farm productivity enhancements toward investments emphasizing food safety and quality, human health and nutrition, and natural resources and the environment. Much of this research could have social payoffs comparable to those from farm-productivity enhancing research; but a slower rate of growth in total spending and the drift of research emphasis will result in slower rates of farm productivity growth and a decline in global competitiveness."

For the developing countries, the decline in productivity-enhancing research in developed countries means that the spillover benefits to them will be reduced, just as climate change and economic conditions become worse. Alston et al note that the situation will be even worse for developing countries given a long lag structure before spillover benefits will occur.

We identify a "productivity growth failure" which is the difference between the historical rate of growth of on-farm productivity (approximately 2 percent) and the current rate of approximately 1 percent. We characterize this situation as "underinvestment" as long as the level and composition of investment keeps on-farm productivity growth below its historical trend and presumed potential.

### 3.3 Incremental investment needed to achieve goals to which one is committed.

There are many prescriptive targets for investment in agricultural R&D. While they all perform a useful function in saying that "we can or we should do more" the way they came to be so popular and what they mean is often forgotten. Table 3 summarizes some of the most common "targets" and the investment needs to achieve them.

For countries with adequate policies and institutions, what additional aid does it cost to reduce income poverty to the desired level? What does this imply in terms of research and other support to the agricultural sector? For countries without adequate policies, what studies and activities are needed to improve policies and institutions? If the focus is uniquely on MDG1, one would have to estimate the additional costs of attaining the health, education and environmental goals that do not come as spillovers from meeting MDG 1.

**Table 3: Common prescriptive targets**

| Target | Argues | Qualifications | Formulation* |
|---|---|---|---|
| Agricultural Research Intensity Ratio | There is some "norm" for reinvestment in the agricultural sector related to size of the agricultural sector | Its components are more instructive than its level; There are different "norms" for different classes of country | AgRE/AgGDP<br><br>Target ranges from 0.2 to 2.5 |
| Maputo Declaration: Commitment to Agriculture | Public Expenditure in Agriculture needs to double to achieve MDG 1. | Determinants of investment needs and growth possibilities are country specific | AE/BUD = 10% |
| Fiscal "Effort" | Even low income country can raise government share in economy to 20% | Fiscal "will" or Fiscal "drag" is country specific | BUD/GDP $\approx$ 20% |
| Growth Rates to Achieve MDG 1 | Overall growth must be accelerated to achieve reduction in poverty and hunger | Need to identify and prioritize sectors that can produce this growth or economy | $\Delta$GDP/GDP = 6% |
| e.g. ASARECA (Omamo et al. 2006) | GDP growth of 6% produces 3% GDP per capita growth (except DRC starting from negative growth) | Implies threefold increase in agricultural sectoral and sub-sectoral growth rates. Differential growth may lead to concentration geographically | $\Delta$AgGDP/AgGDP $\approx$<br><br>Ranges from 4.3% to 6.6% |
| Climate Change Adaptation<br>(e.g. Oxfam, World Bank) | Urgent Adaptation and Mitigation ; Net addition to current aid | "Research" includes more robust estimates of economics of adaptation, study of best practices, and an intensive action learning phase. | US$10-40 billion (WB)<br>US$50 billion (Oxfam International 2007) Annual Requirement |

Note: Where AgRE = Agricultural Research Expenditure; AgGDP= Agricultural Gross Domestic Product; BUD = Government Budget (Public Expenditure); and AE = Public Expenditure on Agriculture. $\Delta$= is the change in the variable since the last period.

* The formulations will be discussed in the next section.

Another example is the Comprehensive Africa Agriculture Development Programme (CAADP) of the New Economic Partnership of Agricultural Development (NEPAD). CAADP's strategy reinstates MDG1 to reduce poverty and hunger by one half by 2015 and postulates that it would require the economy to grow at 6 percent per annum. As one of the largest sectors, agriculture must strive for a growth rate approaching this level (with possibilities of growth widely different regionally and by commodity sub-sector). As a level of commitment by policy makers, the Maputo Declaration called upon governments to raise their expenditures on agriculture to 10 percent of GDP. The simplicity of the target "raise the rate of growth of GDP to 6 percent" belies the complexity of the task of getting there and raising expenditure on agriculture to 10 percent of national budgets may be necessary but is not sufficient. The critical question is: if the necessary changes in policies and institutions are forthcoming, how much additional financial resources will be needed to achieve the 2015 goals.

CAADP calls for increasing investment in four identified pillars as follows:

1. Extend area under sustainable land management and reliable water control (US$37 billion)
2. Rural infrastructure and trade-related capacity for market access (US$37 billion)
3. Increase food supply through a) policy, technology and farm services (US$7.5 billion), and b) disaster and emergency relief and safety nets (US$42 billion)
4. Agricultural Research, Technology Dissemination and Adoption (US$4.6 billion).

Africa would commit itself to:

- Progressively increase its domestic contribution from 35 percent to 55 percent by 2015
- Increase the private sector contribution
- Double the current annual spending on agricultural research within 10 years. (Beintema and Stads (2006) calculated that this means an increase by an average of 10 percent per year; substantially higher than the average annual growth rate of 1 percent that occurred during the 1990s.)
- Invest 10 percent of government budgets in agriculture.

A third example is the strategic priorities study done by the Association for Strengthening Agriculture in Eastern and Central Africa (ASARECA); a sub-regional organization regrouping 10 countries of the region. It carried out an analysis of the possibility of creating a regional strategy for the ten member countries that would meet the MDG with respect to hunger (Omamo et al. 2006).[7]

The study concluded that under the default "business as usual" scenario, none of the 10 ASARECA countries will achieve the 6 percent growth in GDP that is needed to achieve MDG1. It was estimated that most countries will produce less than 3 percent growth in agriculture (based on historical trends and allowing for rapid growth in some countries recovering from civil war). Other development goals, such as food and nutrition security, will remain out of reach. Meeting the goals would demand a trebling of growth rates from the current situation. Not all commodities and all regions have the potential to contribute equally.

The ASARECA study had the beneficial effect of focusing attention on the supply side and highlighted the information gaps. In the absence of field data on the various agro-ecological zones (or the time to generate it), IFPRI used crop models that predicted the expected performance of different commodities in according to soils, topography and rainfall. Looking at the drivers of demand in the region, its multi-market model helped demonstrate that regional staples, livestock products, fruit and vegetables would have the greatest impact on poverty reduction. Milk and cassava were seen as having the largest GDP growth but this would concentrate growth in a small number of countries. The study underlined that agricultural productivity growth alone would be insufficient to meet poverty reduction targets; the region would require growth in non-agricultural sectors and improvement in market conditions. This follows naturally from their identification of the areas for strategic investment as those which are of high potential, low population density and low market access, i.e. areas that require significant investment in infrastructure, markets, adaptive research and scaling up of technology.

## SECTION 4: REALISTIC TARGETS SEEN FROM THE "SUPPLY SIDE": ANALYZING THE AGRICULTURAL RESEARCH INTENSITY RATIO

Placing a country's agricultural R&D efforts in an internationally comparable context requires measures other than absolute levels of expenditures. The most common research intensity indicator is the Agricultural Research

[7] A "development domain" is a homogeneous area characterized by its production potential, access to markets and population density. Investment requirements will be different among the development domains.

Intensity Ratio (ARI). It the ratio formed by the sum of agricultural R&D investments (AgRE) over the agricultural gross domestic product (AgGDP). For two decades the ARI was held up as an instrument of coercive comparison: if a country's neighbor with similar characteristics had a higher ARI, the presumption was that the country was not trying hard enough to support agricultural research.

The ARI first appeared in a World Bank sector paper on Agricultural Research in 1981[8] The authors were looking for a target figure that would establish a "norm" to which national agricultural research systems could aspire. Without an empirical basis from the developing world, they borrowed the estimated investment in science and technology investments in developed countries (around 2 percent) and this became the target figure. But this target proved to be unrealistic for low income developing countries largely due to competing claims on a low fiscal capacity and the large weight of the agricultural sector in the economy. Moreover, this target did not account for the more limited opportunities for innovation in developing countries (Roseboom 2004). Finally, the expectation that agricultural R&D investments would continue to grow at the high rates of the 1980s was not met. A more realistic research intensity target of 1 percent has been recommended[9] in more recent literature (for example, Pardey and Alston 1995; Roseboom 2004; Casas, Solh, and Hafez 1999).

### 4.1 Trends in the Agricultural Research Intensity Ratio (AgRE/AgGDP)

The average ARI for developing countries fluctuated slightly around 0.56 percent during 1981–2000 (Figure 7). This is often attributed to the fact that the denominator, agricultural output grew at the same pace as total public agricultural research spending, In contrast, the average ARI for the high-income countries as a group increased considerably during this two-decade period. In 2000, high-income countries spent a combined $2.35 on public agricultural R&D for every $100 of agricultural output, whereas they spent $1.51 per $100 of output in 1981. More than half of the industrialized countries for which data are available had ARIs in 2000 than in 1991. Most countries in the samples for the Asia–Pacific and Latin American and Caribbean regions also increased their intensity ratios (Beintema and Stads 2008; Stads and Beintema 2009). Only 6 of the 26 countries in Sub-Saharan Africa, however, reported higher ARIs in 2000 than in 1991 (Beintema and Stads 2006).

The use of ARIs is not always appropriate because they do not take into account the policy and institutional environment within which agricultural research occurs or the broader size and structure of a country's agricultural sector and economy. Human and capital investments have a fixed base component, regardless of the size of a country's population, especially when facilities and services are dispersed across broad areas. Furthermore, a number of countries conduct research in areas related to the agribusiness sector, whose production value is counted as manufacturing not agriculture (and hence is not included in agGDP). More importantly in this context, an increase in the research intensity could mean not a higher level of investment, but rather a decrease in agricultural output—the case for a number of high-income countries during the 1990s.

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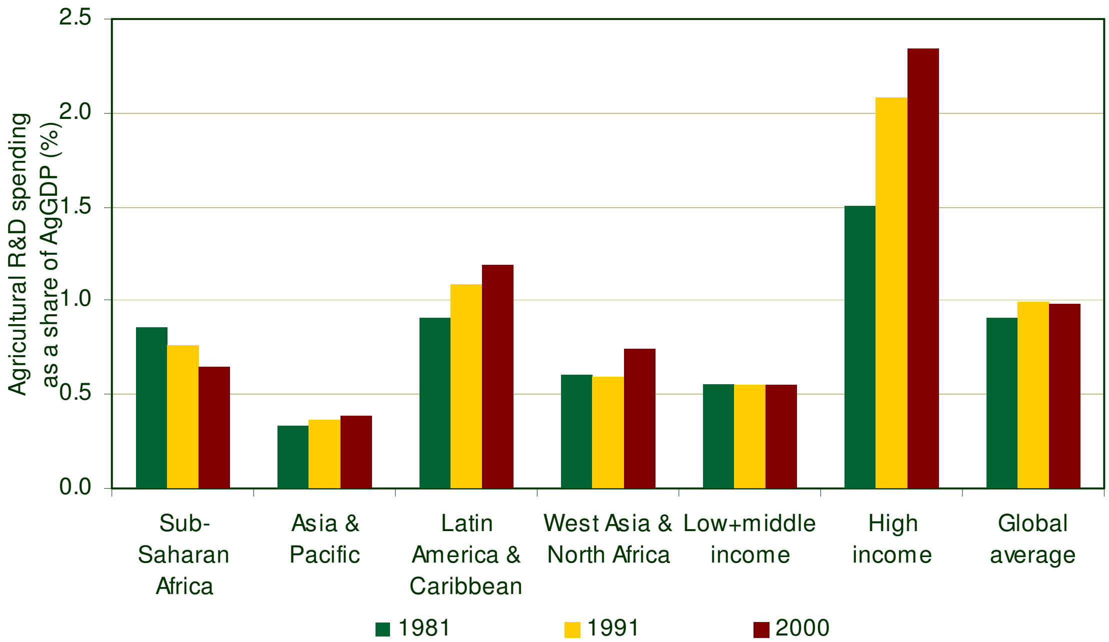
[8] For many observers, the 1980s was the "decade of the NARS" that saw the creation of new national institutes and consolidated national systems in Africa, experiments with "fundaciónes" in Latin America and second generation council models in Asia.

[9] It is "recommended" in the sense that it could be attained by even poor countries if all the priority and institutional factors were functioning as desired.

**Figure 7: Intensity ratios of agricultural R&D spending, 1981, 1991, and 2000**




Sources and Notes: See Table 1.

A number of countries, such as China and India, continue to have relatively low ARIs (Beintema and Stads 2008). Nevertheless, both of these countries have significantly increased their agricultural R&D investments over the past decade or so, such that their agricultural research systems are well equipped in terms of both infrastructure and human resources. Specific areas, however, may require further investment. Consequently, ARIs need to be considered within the appropriate context of investment growth, human resource capacity, and infrastructure.

While it is clear in cross-section that rich countries have higher ARIs than poor countries, it will be necessary to go into the budget detail country by country to understand what its driving this increase and its implications for the contribution of research to growth and poverty reduction. (Elliott 1995).

#### 4.2 What do trends in the ARI tell us about research "effort"?

The ARI by itself can only be the start of a discussion: it is necessary go beyond the "reinvestment in agriculture" ratio by creating an identity that decomposes the ARI into four meaningful components as shown in Figure 8.

**Figure 8: Agricultural Research Intensity Ratio: An identity**

$$\text{ARI} \equiv \frac{\text{AgRE}}{\text{AgE}} \times \frac{\text{AgE}}{\text{BUD}} \times \frac{\text{BUD}}{\text{GDP}} \times \frac{\text{GDP}}{\text{AgGDP}}$$

- ↓ Priority to Research in Agriculture
- ↓ Priority to Agriculture
- ↓ Fiscal Capacity
- ↓ Structure of the Economy

Source: Adapted from Elliott (1995).

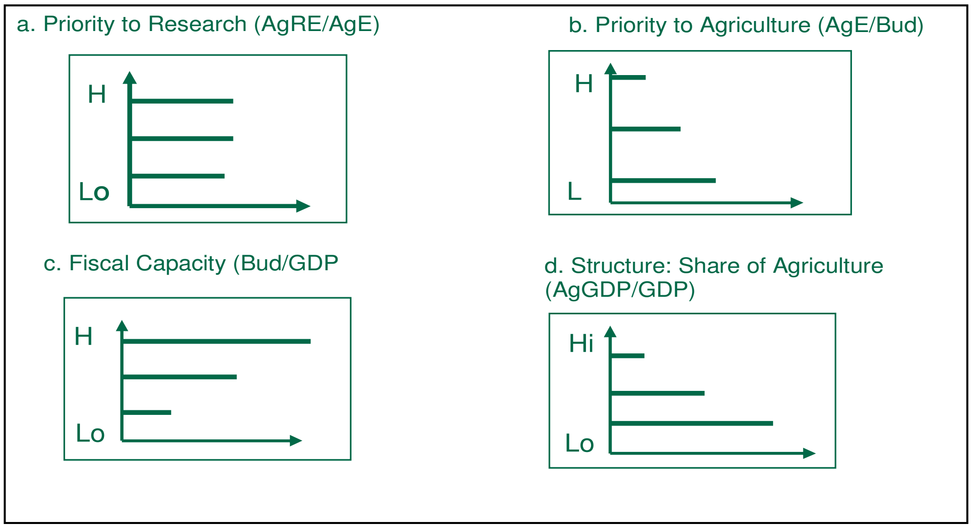
The four meaningful elements in this identity are:

1) *Priority to agricultural research:* the share of agricultural research in total agricultural expenditure (AgRE/AgE)
2) *Priority to public agricultural expenditure*: the share of public expenditure on agriculture in total public expenditure (AgE/BUD)
3) *Fiscal Effort (or Fiscal Capacity)*: the share of public revenue and expenditure in the Gross Domestic Product (BUD/GDP)
4) *Structure of the Economy*: the inverse of agriculture's share in the Gross Domestic Product (GDP/AgGDP).

Each of the elements in the identity is a ratio so the ARI ratio itself is independent of the unit of measurement for each of the elements. Each of them has its own drivers which we analyze as determinants of a country's "efforts" in agricultural research.

Figure 9 represents in schematic form each of the elements in the ARI identity arranged by income class of country (low, middle, and high) (Elliott and Pardey 1988; Elliott 1995).

**Figure 9: Determinants of ARI by country income group**




Note: Y Axis: level of country income per capita; X Axis: Ratios as defined

We present this schematic decomposition of the ARI components (based on the first round of collecting agricultural R&D investment data in the mid-1990s) because it highlights the structural problems low income countries have in raising their ARIs.

1. The share of expenditure on agricultural research in total agricultural expenditure is fairly similar across income levels of country (upper left quadrant). This indicates that low income countries do see the importance of research.
2. While total expenditures on agriculture are low in absolute terms in low-income agriculture-based economies, they represent a higher share of total public expenditure than in wealthier countries (upper right quadrant). The problem is simply that agriculture is also being used to finance the rest of the society.
3. The fiscal capacity (tax collections, public budgets) is a much smaller share of gross domestic product in low income countries than in higher income countries (lower left quadrant). The tax bases are more limited and focus on commodities that have easily identified points of sale.
4. The share of the agricultural sector in the economy falls with rising income (lower right quadrant). In transition and high income countries, non-agriculture can begin to support agriculture.

Recognition of the structural problems does not absolve lower income countries from striving to meet agricultural expenditure targets such as the CAADP 10 percent of budgets (ARI Component 2).

The movements in the ARI at a country level require very country-specific analysis of the drivers of each of these elements. Policy makers' commitments to invest more in agricultural R&D can be measured against the realism of their targets, the coherence of their strategy and priorities, their political and fiscal capacity and the weight of the sector they are trying to move. In the most developed countries, ARIs are rising, but this the result of lower growth rates in AgGDP compared to agricultural R&D investments and not an increase in the absolute levels of agricultural R&D investments. As with the growth of higher education expenditures with rising income, one might ask if this investment is all productive or includes some element of income-elastic consumption of research made possible by rising fiscal resources and a declining share of agriculture in the economy. Countries in the middle income group, where non-agriculture is growing, have an opportunity, if taken, to shift tax burdens away from agriculture, invest in infrastructure and other public goods and improve incentives that reinforce agricultural development. This becomes easier as the share of agriculture in the economy falls. In low-income, agriculturally-based economies, it is difficult to raise the ARI where the fiscal base is small, the size of the agricultural sector is large and the relative cost of a researcher is high.

In the following sections, we highlight some issues with "underinvestment" in research that have their origin in each of the four components of the ARI. As yet, there is no structured, cross-country information that can "unpack" each of drivers of the ARI. This has to be done at the country level at the order of policy makers who want to understand their points of intervention to improve their investment in agriculture.

#### 4.2.1 Priority to research: the Share of Agricultural Research within all Public Agricultural Expenditure

The first determinant of the ARI is the priority to agricultural research within the overall effort to develop agriculture.

In low income economies, studies by IFPRI have suggested that agricultural research continues to be the most productive investment in support of the agricultural sector followed by education, infrastructure and input credits. "Disaggregating total agricultural expenditures into research and non-research spending reveals that research had a much larger impact on productivity than non-research spending" (Fan and Rao 2003).

Donor programs, especially in Africa, can have an important impact on allocation of resources. Programs for Highly Indebted Poor Countries (HIPC) were aimed at social goals. Public Expenditure Reviews pointed out that this affected the selection of projects within sectors, including agriculture (Bevan 2001).

The domestic political economy of budget allocations needs to be better understood. For example, in India the overall public expenditure on agriculture has remained at approximately 11 percent of the budget while the share of subsidies for fertilizer and electricity, and support prices for cereals, water and credit have steadily risen at the expense of investment in R&D, irrigation and rural roads (World Bank 2008b; Beintema Stads 2008b).

In some of the more scientifically advanced middle income countries, the higher-education sector has become a major player of agricultural research – Argentina, Costa Rica, Honduras, Mexico and Uruguay, for example, higher-education sector accounted for more than 40 percent - their government funding comes mostly from the ministries of education. In a number of other countries funding for agricultural research is allocated through the ministry of Science and Technology. In South Africa, for example, funding for the Agricultural Research Council comes through a Council of Science and Technology (with input from the National Department of Agriculture).

In North America, the changing composition of agricultural research expenditure has been a new concern: the share of research oriented to farm-level productivity-enhancement has fallen as low as 60 percent (Pardey 2009; Alston, Pardey and James 2009; Fuglie 2007).

Without contesting the value of research investment beyond the farm gate, the authors are concerned about the long term slowdown in productivity growth at the farm level for three reasons: 1) cumulative loss in productivity growth translates into a significant loss of future income; 2) there is an accompanying loss of potential spillovers to neighboring states (which may have accounted for as much as 50 percent of measured research benefits), and 3) the potential loss of new research discoveries that will be needed 10-20 years from now as both the world confronts the impact of climate change:

> "Given research lags that may be as long as 10-20 years, the effect of this slow-down in developed countries will become apparent in the future when scarcity of land and water, the impact of climate change, and population pressure will become major problems for developing countries. The stream of research outputs which have travelled fairly freely will be reduced significantly." (Alston et al 2009)

Recent studies in Canada have also documented a slowdown in productivity growth linked to declining public research investment as well as structural changes in the sector that have led to calls for more public sector research expenditure.

- Veeman et al. (2007) found that the R&D expenditure for Canadian agricultural research has shown no growth since 1990 and that the prairie crop sector TFP growth has fallen to an average of 0.51 percent per year for the 1990 to 2004 period, which is much lower than historic rates of close to 2 percent per year.
- Gray and Weseen (2008) argue that this slowdown in productivity growth highlights a need for more effective research expenditure.
- While noting that the private sector has filled the applied research gap in key crops, the Canadian Grains Council (CGC 2008) argues that the private sector has concentrated on rDNA technologies which detract from sharing and coordination. It emphasizes, therefore, the importance of public sector research in 1) sharing of discoveries, 2) developing polices that protect plant breeders, small seed producers and niche developers; and 3) facilitating greater collaboration among public and private sector research partners.

The changing composition of agricultural research expenditure is also true for some middle income countries (e.g., Argentina and Uruguay) where research into food safety, food technology and processing are budgeted to the national agricultural research institute. However, since the increase in GDP occurring further down the value chain is counted in the manufacturing sector, the rise in ARI is partly an accounting phenomenon.

#### 4.2.2 Priority to Agriculture: The Share of Agricultural Expenditure in Total Public Expenditure (AgE/BUD)

The second component is the share of agriculture in total public expenditure. This ratio is subject to many different drivers:

- The influence of the domestic political economy. In their review of Medium Term Expenditure Frameworks, Akroyd and Smith (2007) point out the difficulties of budgeting in a "neo-patrimonial political model" and cite Palaniswamy and Birner (2006) on political challenges to increased spending on agriculture. These challenges include the low political voice of farmers, lack of knowledge of agriculture's potential for pro-poor growth, and possibly negative experiences of donors and governments with prior agricultural programs.
- The impact of donor programs. Fan and Rao (2003) pointed out that structure adjustment programs increased the size of government spending but not all sectors received equal treatment. In Africa, expenditures on agriculture, education and infrastructure all declined as a result of structural adjustment programs.

In sub-Saharan Africa, CAADP reports that seven countries have reached or exceeded the Maputo target of expenditure on agriculture of 10 percent of the budget (CAADP 2009).[10] For agriculture-based economies, the difficulty lies in the next two components: fiscal capacity (the share of tax collections and expenditures) and the sheer importance of the agricultural sector in the economy. For transforming economies, the opportunity arises to shift tax collections to growing bases in non-agriculture and to begin net reverse flows of public funds to the sector. It is in the transforming economies where fiscal policies can make or break a pro-agriculture strategy. It is with this factor in mind that we turn to the "fiscal effort" or "fiscal capacity" of a country.

#### 4.2.3 Fiscal Effort: The share of the Government in the Economy. (BUD/GDP)

A government that can raise and spend 20 percent of GDP through tax collections can do more than a government that raises and spends only 12 percent. This includes, among other things, spending more on agriculture and agricultural research. How a country raises its revenues and how it spends its budget are

[10] The seven countries are: Mali, Madagascar, Malawi, Namibia, Niger, Chad and Ethiopia.

specialized fields in their own right. In this section, we are concerned with policy decisions that should involve some input from agricultural policy advisors.

Let us look first at the revenue side. The question of whether a country's fiscal effort and taxation of agriculture is appropriate can only be answered in the light of the specific constraints facing the country. The constraints could be the nature of taxable bases, incentive structures, the fiscal structure and the fiscal culture of the country. The following are common issues in designing fiscal policies with agricultural development in mind. :

- *Taxable bases*. Countries with agriculture as their principal resource have historically overtaxed the sector through biased macroeconomic policies and export taxes and marketing board surpluses. Oil- or mineral-rich countries with large agricultural populations have an opportunity to free agriculture from poor terms of trade and local taxation that discourage production. Failure to do so is often the cause of countries suffering from the "curse of wealth".
- *Fiscal structure*. Decentralization of fiscal responsibility to state and district levels may be a positive factor in raising revenue by bringing services and taxation together in the minds of the population. However, districts may also introduce levies on local agriculture and trade for revenue purposes that are unnecessary disincentives to development when federal grants could be substituted.
- *Fiscal culture*. Low revenue collection and low government services may result from a variety of circular problems and pathologies: low tax rates, excessive exemptions, lax tax administration, widespread non compliance and corrupt; or problems of central versus decentralized accountability. Turning the culture around may be a long term effort.
- *Fiscal returns on public investment.* Easterly (2007) argues that planners have to be aware of the fiscal effects of public investment. Benefit-cost analysis focuses on social costs and benefits but we should not be unaware of the fiscal returns and benefits of an early payback out of increased production and exports.
- *Impact of taxes on key sectors.* In the post-conflict Ugandan economy, for example, the World Bank decided that raising Uganda's fiscal effort above its low 12 percent would have been counterproductive at a time when attracting private sector re-investment in key agricultural activities was crucial for post-civil-war recovery. Future tax collections would come from expanding the base rather than raising the average rate of taxation. (Kreimer et al 2000).

The other side of the government's role is the efficiency of its expenditure. Do the projects meet all the priority criteria, does the budget process allocate funds in that direction and is this the way the funds get spent? In the remainder of this section we look at the effectiveness of public expenditure in agriculture and its link back to "underinvestment" and proposals for dealing with it.

We start with a few general observations:

- It is easier to make progress on the side of revenue reform than on the expenditure side. It only takes a handful of people to design a regulation or a tax reform but it is impossible to subject all activities to a benefit cost analysis at the project level. Such detail is necessary because it is a big mistake to lump all roads (or for that matter all agricultural projects) into one bundle and say "we do roads and agriculture" (Harberger 2009).
- Agricultural research organizations have assimilated the tools of planning and priority setting; however, they are largely absent from budget discussions where the trade-offs are made. Decision-makers rarely have the time or information to make informed choices between projects that have different fiscal and social profiles.
- Donor programs, especially in sub-Saharan Africa have had an impact on broad priorities but have not necessarily been able to control expenditures.

The World Bank introduced Medium Term Expenditure Frameworks (MTEFs) as part of the Poverty Reduction Strategy Programs (PRSPs). They were supposed to ensure that expenditures were driven by policy priorities. Various reviews have highlighted their successes and failures:

- The MTEF in Uganda as been successful in shifting expenditure composition, most notably in favor of education, as well as protecting priority sectors against cuts. It has been less successful at ensuring that budget allocations translate reliably into actual expenditures (Bevan 2001).
- The Nigeria Agriculture Public Expenditure Review pointed out seven areas of concern including discrepancies between policies and expenditures, off-budget funds, lack of information about the functional areas of public spending in agriculture, and poor data quality for planning and impact analysis (Tewodaj et.al 2008).
- They failed to link budgets with strategies and policies; spending patterns were not pro-growth or pro-poor; there was a high degree of centralization in spite of decentralization plans; there was low execution capacity; donor funding was not integrated and there was poor tracking and monitoring. (Fan 2009).

As with any budgetary and control mechanism, there were loopholes in the process: ring-fencing certain types of expenditure (e.g. drought relief); supplementary budgets, and donor support that bypassed the mechanism. In the final analysis, it was concluded that the reform of budgetary processes requires major cultural changes for some countries and the development of capacity for implementation.

#### 4.2.4 Towards more effective financing of research: the interaction of revenue collection and allocation mechanisms.

Before leaving this somewhat structuralist view of the ability to finance research, we note that the source of funding affects the nature of the research that is done. Partly in response to the above problems, governments and donors have been searching for effective and innovative funding mechanisms that will result in more efficient and effective research agencies and systems. The school of "new" public administration" argues that not all public goods needs to be produced by the public sector itself and that in research we deal with many cases of "impure public goods". This opens up both investment in and delivery of quasi-public R&D results through many forms of partnership with interested producers and beneficiaries.

Echeverria and Beintema (2009) define effective financing as "one that increases the average returns of current levels of investment in agricultural research and that also attracts complementary investment from additional sources. An effective funding mechanism will then be the one that allows optimum use of research infrastructure to execute the research." Because of the under-investment in agricultural R&D, policymakers and research managers will need to find a right mix of various financing mechanisms in addition to the direct allocations from central and/or regional public budgets. As mentioned earlier that government support to agricultural R&D has stagnated or declined in a large number of countries, especially when measured in inflation adjusted terms. For a number of countries, they have hampered the performance of agricultural R&D agencies because actual disbursements had fallen behind earlier budget allocations.

Echeverria and Beintema (2009) list a number of alternative funding mechanisms which tie sources of funding and prospective beneficiaries of research closer together or permit project level control of expenditure:

1) Competitive grants, which often complement direct government budget allocations and have played an important role in mobilizing research actors around specific outputs and improving the efficiency and accountability of research outputs and actors. On the other hand, they may not be as effective as core funds in ensuring long term capacity. Furthermore, competitive

funding schemes mostly fund specific projects and often cover only their operational costs and not salaries or maintenance of the institutional infrastructure.

2) Producer check-offs and export levies, which are mostly collected through taxes raised on export or production of commercial crops. One benefit is that farmers are more involved in setting the research priorities. They finance "club goods and services", which is a form of restriction of benefits. Such para-fiscal levies come from the industry itself but may not be available in times of major crisis when they are most needed.
3) A number of agencies and countries have been successful in commercializing their research outputs, often through partnerships with the private sector. One important downside is that in many countries the revenue from commercialization goes directly into the government's treasury so there is limited incentive for research agencies to sell research outputs and services.
4) The debate about program versus project funding continues (see also the paragraph on CGIAR investment in section 2). When donors talk about shifting financing from the supply side (institutional commitment) to financing "results" it is often a prelude to a reduction in overall level of funding.

#### 4.2.5 The Structure of the economy: the inverse of the Share of Agriculture in the Gross Domestic Product (GDP/AgGDP)

The final element underlying movements in the ARI is the inverse of the share of agriculture in gross domestic product.

In a successful transformation, the share of agriculture in GDP, the share of population in agriculture in the total population and the dependence on agriculture as the source of development finance falls. This is made possible by rising productivity in agriculture and the transfer labor to other sectors.

It should be in the transforming economies that agricultural and fiscal policy can make the breakthrough to more sustainable support for agricultural research: 1) better macro policies usually improve the opportunities for agriculture, 2) new tax bases outside the agricultural sector help remove some of the fiscal drag caused by agricultural taxation, and 3) large population in non-agriculture can make significant contributions to a declining population in agriculture.

The policy lesson for governments would be to maintain a macro economic balance and the positive environment for agriculture that it creates. Productivity increases will free both land and labor and policies should facilitate the movement of people out of agriculture as they are no longer needed on farms to feed the country. The point is not to maintain millions of small farmers but to eliminate poverty, with recourse to safety nets where agricultural and overall growth is not enough. (Valdés and Foster 2005).

## SECTION 5 CHALLENGES AND ESSENTIAL INVESTMENTS

### 5.1 Investment options targeting special non-productivity objectives

This paper has basically argued that research oriented at enhancing farm-level productivity has being shown to have high rates of return and make generally positive contributions to environmental and social objectives. Other policy instruments can be designed (e.g. safety nets, facilitation of migration, payments for the true value of resources and ecosystem services) to ensure that society gains.

The IAASTD (2009) has identified some of the directions in which new research can make a direct impact on sustainability and social goals:

**Table 4: Investment options as outlined in the IAASTD Global Report**

| Goal | Investment required to: | Examples |
|---|---|---|
| **Environmental sustainability** | 1. Reduce the ecological impact of farming systems | Management practices; reduce use of fossil fuel, pesticides, fertilizer; biological substitutes for fossil fuels and chemicals |
| | 2. Enhance systems that are known to be sustainable | Social science research on policies and institutions |
| | 3. Support traditional knowledge | Non-conventional crops and breeds; traditional management systems |
| **Hunger and poverty reduction** | 1. Target institutional change in organizations; | Planning with pro-poor perspective |
| | 2. Include equity in planning and pro-poor policies | Access to resources; benefit sharing from environmental services |
| **Improving nutrition and human health** | 1. Improve nutritional quality and safety of food | Co existence of obesity and micronutrient deficiency ; pesticide residue; SPS standards |
| | 2. Control environmental externalities | Pollution, overuse of antibiotics and pesticides, on-farm diversification |
| | 3. Ensure better diagnostic data and response to epidemic disease | Zoonotic diseases an increasing problem along with dangers of pandemics; prediction of disease and pest migration with climate change |
| **Economically sustainable development** | 1. Enhance research on water use and control of pests and diseases | Both areas affected by population growth and climate change |
| | 2. Productivity-enhancing research to save land and water as limiting factors | Total factor productivity benefits from higher yields per hectare and more crop per drop. There is need to address the most limiting factors |
| | 3. Prices and incentives promote proper social use of resources | Pricing policies and payment for ecosystem services will make land and water use more efficient |
| | 4. Advance basic research in genomics, proteomics, nanotechnology | Historically high rates of return to basic research; applications may spillover freely to developing countries in the future |

Source: Adapted by authors from IAASTD Global Report, Table 6.2 (Gurib-Fakim et al. 2008, p 381-84) and from discussion in Chapter 8, Section 4.

### 5.2 Investment in basic capacity to do research and development

In this final section, we want to highlight three basic needs:

1. The need for basic studies and methodologies. Even a country that is considered too small to have a full-fledged NARS needs to invest in knowing a) What is the country's potential given its water resources, soils and climate; b) Where it can access knowledge, science and technology to realize its potential; and c) Sufficient advanced science to be a good negotiator of partnerships and purchaser of technology.
2. The need to address capacity needs in a systemic way that includes balanced growth of research institutes with universities and other stakeholders upstream and downstream.
3. The need to integrate networks at the global, regional and sub-regional levels while escaping high transactions costs and dispersion of effort.

While there are many other issues, this paper highlights these three areas of "underinvestment"

### 5.2.1 Basic studies and methodologies

Decisions about investment ultimately come down to two judgments: what are the possibilities of advancing knowledge and technology and what is the value to society of the new technology (Ruttan 1982)? Processes for making such decisions are increasingly a mix of supply-led analysis of expected gains prepared by scientists and a participatory (bottom-up) evaluation of the usefulness of the knowledge to clients and beneficiaries. Both the governance of the process and the nature of the evidence have to be appropriate to the level and nature of the decision to be made.

The need for basic studies is, for example, apparent in the three approaches being adopted to address priorities and strategies for global agricultural R&D (CGIAR 2009):

1. "Trust in models" includes definition and characterization of "systems" that will form the building blocks for assessing agricultural, environmental, and institutional/policy research challenges and opportunities , as well as evaluation of the nature and scale of potential R&D-induced impacts (by system) according to scenarios and parameter estimates established during the elicitation process.
2. "Trust in front-line researchers" designs and implements a science-focused elicitation of appropriate technical, institutional and social variables to be used in assessing the potential impact of research-induced change.
3. "Trust in wisdom" will draw on consultation with highly recognized research and policy leaders as reviewers and stakeholder and partner dialogues.

The above will need better tools and information in all types of areas. For example, models and spatial analysis tools can be used to identify homogeneous development domains. Modeling can substitute for expensive multilocational trials and can be used to extrapolate results for planning. However, the basic information needs to be collected and processed and results ground-truthed. The need for basic hydrological, meteorological and soils studies goes beyond the needs of "agricultural research" and needs to be provided through other budgets.

Furthermore, there are emerging challenges that are likely to grow with climate change, population growth and increasing resource scarcity. These include expansion of pests and disease and the dangers of pandemics that cut across several ministries. The current level of agricultural research on these issues can be considered "underinvestment" even if it is congruent with the current importance of the problem. Given that agricultural and land use practices contribute 32 percent of global emissions of GHG (Stern Report, 2007) the need for better understanding of agriculture's role in adaptation and mitigation is clear.

In this respect, the IAASTD highlights the need for strategic cross-disciplinary methodological research on environmental sustainability and poverty reduction:

> "The first important need for AKST investment is for social and ecological scientists working with other scientists to develop methodologies and to quantify the externalities of high and low external input systems from a monetary perspective as well as from other perspectives such as the concept of energy flows used in energy evaluations. Evidence on these externalities' potential implications on food security also needs to be analyzed."

The call is for a discussion of values as well as technical solutions. Both neoclassical economists and agro-ecologists agree that the issue of pricing of resources and the value of ecosystem services has been under-studied. The call for more research is not just about technical solutions of markets, taxes and subsidies but about the framing of the issues. This has implications for the way in which people are trained, the discussion of the following section.

### 5.2 2 Capacity in Agricultural Research and Higher Education

Investment is needed to reverse the general underinvestment of the last decade and meet the various political targets and prepare for the emerging challenges outlined in the previous two sections, more investment is needed. However, this presumes that there is either sufficient research capacity to address these targets or the commitment to invest in creating it. Moreover, the rate at which research capacity can grow is linked to the strength of the higher education system. In many countries, this subsystem itself requires re-tooling. Targets which project annual growth in current research expenditures of 10 percent or more need to be reviewed carefully so that good intentions do not result in wasteful expenditures that press against scarce human and institutional resources.

Various organizations and publications have expressed concern in this regard.

- An assessment of the national agricultural research and extension systems in Africa, which found many agencies with professional staff shortages, established positions remaining vacant, and an aging pool of professional research staff (FARA 2006).
- A recent study by the ASTI initiative, covering 14 countries, showed that although professionals engaged in agricultural research and higher education has increased by 20 percent during 2000/1 to 2007/8, two-thirds of this increased capacity was trained only to the BSc level (Beintema and Di Marcantonio 2009).[11]

This is a worrisome trend, especially in light of the increasing costs of postgraduate training abroad—and the diminishing relevance of these programs to Africa. This calls for an expansion of postgraduate level training in agricultural sciences (World Bank 2007).

Although the number of universities and faculties in agricultural sciences has grown substantially during the past three decades, many suffer from staff shortages, insufficient funding, declining student enrollments, outdated curricula, and a continuing focus on undergraduate studies (Beintema, Pardey, and Roseboom 1998; IAC 2004b; World Bank 2007). Donor support for training programs waned in the 1990s, and African governments have largely been unable to fund training themselves (Beintema, Pardey, and Roseboom 1998). Eicher (2006) has highlighted the sequential rather than balanced way in which agricultural research, extension and higher education have been addressed in sub-Saharan Africa. The authors agree that a balanced development of the agricultural knowledge system is needed.

There are some initiatives to address this problem. The Rockefeller Foundation established a program to train future teachers of biometrics African universities to be able to meet the demand for this basic research skill that had been neglected in recent years. A number of countries have more recently established postgraduate training programs, but in general they are still small in terms of student enrollments. Increasingly, there is recognition of the need to expand Africa's postgraduate training in agricultural sciences at both national and regional levels (World Bank 2007).

Current discussions of capacity go beyond the usual discussion of scientific and technical skills. Both the review of Agricultural Education and Training by the World Bank and reviews of research institutions mention three needs: 1) scientific capacity; 2) "soft skills" for innovative work across institutional boundaries, and 3) institutional capacity to learn and change. We have addressed the first category where MSc and PhD students are an essential part of the research infrastructure.

In the "soft skills, we find post-graduate education and evidence of personal skills that facilitate working across ministerial and sectoral boundaries. Institutional policies that facilitate cross-institute and cross-sectoral collaboration are being put in place between research institutes and universities. Furthermore, policies should be

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[11] Interestingly is that about half of the capacity increase were women resulting in an increase in the share of women in professional staff at agricultural research and higher education agencies in these 14 countries from 18 percent in 2000/1 to 24 percent in 2007/8 (Beintema and Di Marcantonio 2009).

put in place that aim to increase the participation of women Given growing concern over declining agricultural research capacity, increased participation in agricultural R&D by women is not only important for gender-balance, but also in order to tap substantial additional human resources for agricultural R&D.

It is necessary to draw attention to these processes because the training lags and transactions costs involved in taking on new agendas affect the rate at which the research system can grow without wasting resources.

### 5.2.3 Policy and the Institutional Architecture for Research

This final section of the paper notes that policies, institutional arrangements and the governance of research all require investments that compete with the performance of scientific and technical research. Attempts have been made to measure the productivity of social science and policy research; to establish the value of institutional changes or management improvement, and to examine the cost of governance. This is where “process is as important as the product” comes up against the assertion of the “burden of high transactions costs”.

As noted in Section 5.2.1, development of a plan requires a process in which the issues are properly framed, information is brought to bear on the issues, different perspectives are integrated and some form of governance mechanism is needed to oversee implementation. We have highlighted the need for better basic information, methodologies and models to support decision-making.

The structure of global agricultural research is undergoing an important period of change. Within the CGIAR, the Alliance of research centers supported by the Group is forming a consortium that will negotiate core functions and mega-programs to be supported by a consolidated donor Fund. It is essential that this Fund provide a guaranteed core on which a sustainable system can be built. In sub-Saharan Africa, bilateral and multilateral donors are promoting the creation of regional research programs and sub-regional centers of excellence in specific areas that go beyond the previous research networks. The development of a more effective global system that meets stakeholder needs is receiving investment of time and resources.

Many emerging problems such as climate change, migratory pests, and pandemics are transboundary in nature and will require new mechanisms for dealing effectively with them.

Legal frameworks, particularly relating to intellectual property and biosafety are affecting the both concentration of research activity and access to strategic genes. New institutions such as the African Agricultural Technology Foundation are set up to facilitate access by developing countries to proprietary technology. Recent attention to biosafety has resulted in regulations that may have unintended consequences in either keeping certain potentially valuable technologies out of developing countries or concentrating ownership further in the hands of large corporations able to bear the costs of passing the process and in countries with large enough markets to justify it. Research into proper frameworks that ensure that developing countries benefit from new science and technology is a priority for investment.

## 5.3. Conclusion

This paper has documented key trends in global investment in agricultural R&D using the most recent data from ASTI and other sources. It has provided evidence that there has been “underinvestment” in agricultural R&D both in terms of foregone benefits and in terms of preparedness to meet established political comments to reduce poverty and hunger. Countries at all levels of development have the fiscal capacity to develop a sufficient system to participate in and benefit from what will, it is hoped, be a coherent and effective global system. By treating the establishment of legal frameworks, institutional arrangements and governance processes as “investments” we will have to keep in mind that the processes must have positive results in terms of established goals. New global challenges will require additional research investments that will only be forthcoming if adequate attention is given to the information, basic studies and human resources in national institutions of research and higher education.

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# EVOLVING STRUCTURE OF WORLD AGRICULTURAL TRADE AND REQUIREMENTS FOR NEW WORLD TRADE RULES

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## ABSTRACT

The recent world food crisis of 2007-08 alerted the world and policy makers to the fact that global agricultural productivity growth has been slowing down, and highlighted the fact that current national agricultural trade policies and the current world trade rules as agreed in the World Trade Organization (WTO) Agreement on Agriculture may not be adequate to prevent such crises in the future. At the same time changes in climate may be precursors of more potential food crises, with significant negative impacts on many poor across the world. This necessitates a reconsideration of the factors that drive long term agricultural trade, and the needs of future global agricultural trade rules.

The objective of this paper is to highlight and analyze several factors impinging on future agricultural trade developments, in order to identify possible needs for future global agricultural trade rules. The paper first documents the recent food events and discusses factors behind these developments. It analyses the pattern of global agricultural market instability over the past 40 years and the factors that may affect it in the futures. New challenges facing the world agricultural trade system are analyzed next. Then a discussion of the growing vulnerability of some developing and least developed countries is illustrated. The paper finally tries to identify areas where the WTO system of rules on agricultural trade may need strengthening or adaptation.

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## 1. INTRODUCTION

The recent world food crisis of 2007-8 alerted the world and policy makers to the fact that global agricultural productivity growth has been slowing down, and highlighted the fact that current national agricultural trade policies and the current world trade rules as agreed in the World Trade Organization (WTO) Agreement on Agriculture may not be adequate to prevent such crises in the future. At the same time changes in climate may be precursors of more potential food crises, with significant negative impacts on many poor across the world. This necessitates a reconsideration of the factors that drive long term agricultural trade, and the needs of future global agricultural trade rules. The objective of this paper is to highlight and analyze several factors impinging on future agricultural trade developments in order to identify possible needs for future global agricultural trade rules. The main point made is that the need to deal with potentially unstable global agricultural markets will necessitate some potentially new world trade arrangements.

The sudden and unpredictable large increases (spikes) of many internationally traded food commodity prices in late 2007 and early 2008 caught all market participants, as well as governments by surprise and led to many short term policy reactions that may have worsened the price rises. Many governments, think tanks, and individual analysts called for improved international mechanisms to prevent and/or manage sudden food price rises. Similar calls for improved disciplines of markets were made during almost all previous market price bursts, but were largely abandoned after the spikes passed. The financial crisis that started to unravel in 2008 has coincided with sharp commodity price declines, and food commodities have followed this general trend. The price volatility has been considerable. For instance, in February 2008, international wheat, maize and rice price indices stood higher than the same prices in November 2007, namely only three months earlier, by 48.8, 28.3, and 23.5 percent respectively. In November 2008, the same indices stood at -31.9, -3.2, and 52.3 percent higher respectively, compared to November 2008. In other words within one year these food commodity prices had increased very sharply in the first part of the year, and subsequently declined (except rice) equally sharply. Clearly such volatilities of world prices creates much uncertainly of all market participants, and makes both short and longer term planning very difficult for all.

The high food commodity prices coincided with high prices for petroleum, and many mineral products, but not with high prices for many agricultural products of export interest to many developing and least developed countries (LDCs) and in particular those in Africa. Hence, the recent commodity price boom may not have benefited, and in fact may have hurt most such economies. Given the size of the external shock, one may question how poor agriculture-dependent economies fared during the crisis, and whether this type of external shock adds to the already vulnerable and fragile state of many of these economies.

Many developing countries and especially those in Africa have always had exports concentrated in primary commodities, and it is well known that these commodities are characterized by volatile world prices. This implies that the terms of trade for most such economies have been volatile. Nevertheless the (negative) impact of this instability on economic performance has not been explored at the macro level until recently (e.g. Collier and Dehn, 2001, Guillaumont and Chauvet, 2001, Collier and Goderis, 2007, Guillaumont and Korachais, 2006, Blattman et. al. 2007). Another issue, also well analyzed, albeit not resolved, concerns the possible existence of persistent negative trends of the prices of primary commodities (for a recent review see Cashin and McDermott, 2006). The combined negative effects of negative trending and unstable terms of trade for African economies is one of the reasons for their alleged negative performance.

A more recent but less analyzed development has been the increasing food import dependence of developing countries and especially LDCs, despite ample natural resources for food production. This trend in itself does not necessarily imply any problems, as increased food import dependence may be a natural tendency during the transition of an agrarian economy to one based more on manufacturing and services, and can be managed if the export income generated by the non-agricultural sectors can pay for the increased food imports. Such trends, which have been observed in several now developed or middle income developing economies, have been the natural outgrowth of their transition to more productive and diversified structures, and have been characterized by increased agricultural productivity. Many LDCs, however, do not seem to have followed this trend, and hence their growing dependence on food imports seems to suggest another structural development that may contribute to vulnerability.

A major issue of LDCs and African economies' fragility and vulnerability is what this increased exposure to food imports implies about food security, and the impact of external food market shocks. The issue depends considerably on the degree to which the vulnerable populations in these countries are exposed to the international market shocks. In other words the issue is whether food insecure households are exposed to international market instability. Here, the evidence appears to be that they are very weakly exposed to international market signals, at least in the short term. The reasons have to do with weak infrastructures, high transactions costs, and government policies. This, however, tends to shield vulnerable agriculture-dependent households from the international markets, which makes them more vulnerable to domestic agricultural income shocks, such as those due to unfavorable weather events. These, in fact maybe more detrimental to these households than the shocks due to external market instability. Hence insulation of food insecure household from international markets can shield them from external shocks but make them more vulnerable to internal shocks. The opposite is the case for households that are well integrated with international markets. This, then, presents a policy dilemma with respect to the optimal degree of insulation of food insecure households from world markets. Keeping food insecure households insulated from world markets makes them less vulnerable to global shocks but more vulnerable to domestic shocks, and the opposite is the case if the degree of insulation is smaller. The optimal degree of insulation then to two types of shocks must depend on the degree of exposure to domestic shocks and global, as well as the relative magnitude of these shocks. Some thoughts on this issue will be made towards the end of the paper.

The plan of the paper is as follows. In the following section we examine the recent food price spikes and food market instability in order to assess whether there are tendencies different than the past ones that may raise new concerns. In section 3 we explore the reasons for world agricultural commodity volatility and prospects thereof. Section 4 discusses medium and longer term developments that are likely to affect global agricultural trade. In section 5 the issue of vulnerability of the food economies of developing countries is taken up. The final section summarizes.

## 2. RECENT COMMODITY PRICE DEVELOPMENTS IN PERSPECTIVE.

Figure 1 indicates the evolution of monthly nominal international prices (index form) of the main traded food commodities since 1990. It can be seen that the main commodities that have soared in late 2007 and early 2008 were dairy, cereals and oils, while sugar and meat prices do not appear to have spiked in any exceptional way, given the trends since 1990. Similarly (and not shown), other agricultural commodities such as the tropical beverages coffee and cocoa, have not exhibited any marked price changes in 2007 and 2008, compared to the 1990-2006 patterns. As of mid-2008 these spikes have vanished, with most indices returning to historical levels.

While, however, the world price changes in some of the basic food commodities appear significant in nominal terms in relation to the trends of the past twenty years, when examined in real terms, prices during the recent crisis appear still considerably smaller compared to the peaks during the previous major food crisis of the mid-1970s. Figures 2-4 indicates the real international prices (deflated by the US producer price index) of the main cereals and oilseeds, vegetable oils and livestock commodities from 1957 to 2008. It can be readily seen that for all commodities indicated, the real prices at the height of the crisis in 2008 were considerably lower compared to the real prices in the mid 1970s.

Another salient pattern evident in the graphs of Figures 2-4 is that the long-term decline in food commodity prices, that appears to have been in place since the late 1950s, seems to have stopped in the late 1980s and early 1990s, with the trend lines indicating steady, albeit still fluctuating patterns. This suggests that there may have been several slowly evolving factors affecting global food markets that gradually created a situation of tightly balanced supply and demand, where a spike was almost inevitable in response to small shocks. Several of these factors have been discussed and analyzed by many authors and think tanks, as well as FAO. They include the following.

1. Growing world demand for basic food commodities, due to growth in emerging economies, such as China and India. This development has been touted considerably by many observers, but in fact it has been occurring gradually for several years, and cannot account for the sudden price spikes. Furthermore, the rate of growth of these countries' demand or utilization of cereals, the most widely consumed and traded food commodities, for food, feed and other non-biofuel uses, has been decreasing rather than increasing. In fact this is compatible and predicted by conventional economic wisdom, which indicates that as incomes rise, the demand for basic foods rises by less than the rise in incomes.

2. Demand of cereals for biofuel production. It is true that a significant amount of production of maize in the United States of America, oilseeds in the European Union, and sugar in Brazil have been utilized for biofuel production, often with help from a variety of support policies and mandated alternative energy targets. This has also been occurring over a number of recent years, and accounts for a significant portion of market demand for these commodities, as well as, via substitution, for indirect demand for several other commodities that compete for the same resources, such as land. As this has been occurring for some time, and helped keep prices increasing and strong overall, it is unlikely to have been a major factor for the sudden price spikes, albeit it may have had amplifying effects in an already tight market.

3. The rise in petroleum prices. Petroleum prices started rising in 2004, and continued rising all throughout the past few years, before sharply declining in late 2008. The reasons are largely demand by fast-growing countries with energy-intensive economies, such as China and India. The oil price increase, apart from pushing costs of agricultural production and transport higher, induced a demand for alternative fuels, which in the context of the rising awareness about climate change created a strong demand for biofuels. This, in turn, translated to increasing demand for agricultural raw material feed stocks for biofuel production. Oil price increases accelerated starting in late 2007 and continued increasing rapidly until August 2008 when they started a rapid decline. Food commodity prices, especially those for biofuel stocks, seem to have followed this trend quite closely, including through the spike period of late 2007-2008 and hence one might induce that there is a close link between oil prices and food prices that may have been one of the main contributing factors to the recent food price spike and subsequent decline.

4. Slowing rates of increases in farm productivity. During the more than thirty years since the last major food price crisis of 1973-75, agricultural prices in real terms have been declining due to fast rates of growth of agricultural productivity (both land productivity as well as total factor productivity). In the more recent period, agriculture has been neglected in most developing countries, as the World Bank's 2008 World Development Report aptly illustrated. The neglect not only involved lower productivity growth, via lower investments, but also the perception that agricultural supplies were not a problem in a world of low prices.

5. The gradual decline in global food commodity stocks. The ratio of end of season world cereal stocks to global utilization appears to have decreased considerably between 2000 and 2008. For two of the major cereal commodities (maize and rice) this decline can be accounted for by the decline in the stocks of China. However, whether including or excluding China, world cereal stock ratios for most cereal commodities have not changed appreciably in the last 20 years. Nevertheless, several major cereal producing and trading countries experienced secular declines in end of season stocks. Irrespective of the source of the decline, however, it is a fact that when commodity markets face lower end of season stocks, they react much stronger to any negative shocks.

6. Commodity speculation. This factor has been highlighted by many analysts and politicians, to the point of blaming the organized commodity exchanges for the price spikes. Speculation is an ordinary fact of life in all commodity markets, and is a necessary ingredient of all commodity trade. Any agent who buys a contract for commodity (in the physical or future markets) with the intention of selling it later for a profit can be considered a speculator. Organized commodity exchanges are important institutions for both market transparency as well as the transfer of market risk from physical markets to speculators, and they guarantee transactions via the underlying clearing houses. It is no coincidence that they have evolved and grown over a period of more that two centuries, as they have been perceived as important institutions for managing market risks. The advent of large investments by commodity funds in recent years has raised new issues about the utility of the organized exchanges as risk transfer mechanisms, and about the role of unfettered speculation in persistent price rises. Detailed analyses of recent events (Gilbert, 2009) have suggested that there is only weak evidence that such investments have contributed to the commodity price boom.

7. Macroeconomic factors. While most commodity market analysts look for commodity-specific fundamental factors to explain individual commodity price spikes, there are systemic macroeconomic factors that affect all commodities that have been very influential. The recent commodity boom has involved most traded commodities and not only agricultural ones. One of the key factors that fueled such a boom seems to have been a period of easy money and loose regulation

of financial transactions, which resulted in a fast expansion of global financial liquidity, a weak US dollar, and low interest rates. It is notable that the previous large commodity boom of 1973-75 was also preceded by a period of expanding global liquidity fueled by large US external deficits and loose monetary policies, much like in recent years. It has been shown by research (Abbott, *et al.* 2008, Mitchell, 2008) that US dollar depreciation has contributed around 20 percent to increases in food prices. Frankel (2008), in turn, has made the argument that low interest rates, themselves induced by monetary expansion, encourages portfolio shift into commodities, and also discourages stockholding, therefore, contributing to commodity price rises. There is an additional factor in explaining the abrupt behavior in food commodity prices in the midst of the financial crisis of 2008. Many researchers suggest that commodities – especially commodity futures – have become a new ‘asset class’. First, returns to commodity futures are negatively correlated with returns to traditional financial assets such as equities and bonds. This relationship indicates that commodity futures offer an attractive vehicle for portfolio diversification that reduces the volatility of portfolio returns. Second, comparisons between returns of commodity futures with those of traditional financial assets, such as stocks and bonds, indicate that investment in commodity futures is profitable. Futures and stocks have similar returns, amounting to about 5.2–5.6 percent per annum. This is twice as high as the return from investing in bonds. These observations suggest that commodity futures are not only regarded as providing insurance against price risk for farmers and food processors, but also as an asset which generates returns and can be used to diversify traditional financial portfolios. Given that the commodity boom of early 2008 came to an abrupt stop in late 2008, followed by subsequent strong price declines, in the wake of the global financial crisis, without substantial changes in the underlying commodity market fundamentals, suggests that macroeconomic factors were important in the recent boom.

The important point to highlight is that most of these factors were slow in developing over several years, but cumulatively they created a situation of tightly balanced world supply and demand for many agricultural commodities. Furthermore, they made the demand for the agricultural commodities very price inelastic. The demand curve for agricultural (and other commodities) is price elastic when there are ample supplies (from both production and stocks) but becomes very inelastic when the overall supplies are small, and there is low capacity of the market to absorb or buffer exogenous shocks. As indicated above both the reduction of global stocks, as well as the macro factors that fuelled demand growth, pushed the supply demand balance of most food agricultural commodities in a territory, where small shocks or small changes in perceptions could have had very strong price effects. In fact the food production shocks that happened were small, exemplified by the fact that global grain production declined by only 1.3 percent in 2006, but then increased by 4.7 percent in 2007, and a further 4.8 percent in 2008, despite the fact that some of the major exporting countries such as Australia experienced very sharp negative production shocks (of the order of 50-60 percent in both 2005 and 2006). Such production shocks are rather normal in global food commodity markets, and have occurred on similar scale several times in the past, without causing price spikes. It then appears that production shocks were not the main factor driving the commodity markets, but rather some of the other factors indicated above.

A factor that seemed to have contributed considerably to the recent short-term price spikes is hoarding tendencies and policies affecting the normal flow of commodities. It is well known that the reaction of many private agents as well as governments at the onset of price rises was destabilizing, in the sense that their actions fueled the demand for current supplies, led by fears of impending basic commodity shortages. In other words when market agents realized that there were inadequate buffers in the global markets to ensure smooth supply flows, they started to behave atomistically, to ensure their own smooth supply flow. This created panic buying and hoarding, even when the underlying conditions did not justify it, thus creating the price spikes. The case of the global rice market is a good case in point, where, despite adequate global production and supplies, uncoordinated government actions, such as export bans, created a short term hoarding panic and an ensuing price spike. The realization in mid-2008 that the situation was not as critical as many thought, led to the opposite effect and a sharp price decline followed.

In the context of the events of the last two years, it is interesting to examine the evolution of world market price volatility. Figure 5 plots the indices of annualized historic volatilities (estimated by normalized period to period changes of market prices) of nominal international prices of wheat, maize, and rice over the previous five decades. The figures also exhibit the nominal international prices on the basis of which the indices of volatility are determined. The reason for the juxtaposition of the two types of information is to examine visually the relationship between the level of commodity prices and the market volatility. It has been known for along time (Samuelson, 1957) that in periods of price spikes, overall supplies are tight, and market volatility should be higher, hence the expectation is that during periods of price spikes the index of market volatility should exhibit a rise as well. .

A most notable characteristic of the plots in Figure 5 is that historic volatility (as an index of market instability) of most food commodities, while quite variable, appears not to have grown secularly in the past five decades. There also appears to be no clear correlation for most commodities between the two major price spike periods, namely 1973-75 and 2007-08 and volatility. During the first boom period, namely 1973-75, volatilities of wheat and maize appear to have increased markedly relative to previous trends. However, this is not the case for rice. During the most recent boom of 2007-08, the volatility of wheat and rice appear to have increased markedly, but not that of maize. While these observations are just visual and need to be corroborated with appropriate econometric analysis, they raise some questions about the alleged positive relationship between the level of prices and the level of volatility.

## 3. FACTORS AFFECTING PRICE VOLATILITY OF INTERNATIONALLY TRADED AGRICULTURAL COMMODITIES AND PROSPECTS

There are two factors that traditionally have been considered the main ones in influencing agricultural market price instability. These are the variability of production, and the level of end of previous period stocks. The more variable is agricultural production, the more one expects to observe large period to period price variations, namely larger volatility. In the same vein, the smaller the end of season stocks, the more any new market developments are likely to affect prices, and hence the more variable is market price.

Figure 6 exhibits trends in the coefficients of variation of annual production of wheat, maize, rice, and soybeans computed for four ten year periods ending in 1999, as well as the most recent period 2000-06, and for the five continents, as well as the world as a whole. The data indicates the magnitude of year to year variability of agricultural production relative to the ten-year average of the relevant period, in order to ascertain whether there appear to be any discernible trends.

Concerning wheat, there appears to be a marked <u>decline</u> in world production variability, and significant reductions in production variability of America (North and South) and Asia, which between them account for 60 percent of global production. It is only Africa, which accounts for a small share of global wheat production (only 3.3 percent), where production variability seems to have increased. Similarly for maize, global production appears also to have become less variable, with no apparent significant positive trend in any continent. Global paddy rice production variability also appears to be declining over time. The trend is similar in all continents, except Oceania, which, however, accounts for only 0.1 percent of global paddy production. The trend in global soybean production variability also appears to be negative, with most continents exhibiting declining or at most non-increasing coefficients of variation. It thus appears that one of the main traditional factors that affects price volatility, namely production variability has become less important over the previous 50 years. Hence this factor, if anything, implies lower overall market volatility.

Turning to end of season stock levels, Figure 7 exhibits the end of season global stocks both absolutely as well as share of total utilization for wheat, maize, and rice, and also the same figures without China for the past twenty years. The first observation is that global end of season stocks of cereals do not appear to have been in 2007-8 much smaller in absolute levels than in earlier periods, notably the early-mid 1990s. Stocks increased considerably and reached a peak around 2000-2001 and then the started declining. The decline continued until 2004-5 and these trends occurred both with and without China. After 2005 stocks appear to have increased or at least not decrease in absolute terms.

Turning to stock to utilization ratios, the most interesting observation from Figure 7 is that the ratios seem to follow the same patterns and turning points both with as well as without China. Also, albeit there appears to be a negative trend in the ratio of stocks to utilization for the world, when one examines the whole 30-year period from 1979 onwards, there is no marked negative trend for the ratios if China is excluded from the world total. In fact for rice, the ratios for the world as well as without China exhibit a slight positive trend.

However, China is an important producing and trading country, accounting for 17-18 percent of global wheat production, 15 percent of coarse grain production and 29 percent of global paddy rice production. It also, and for the most recent years for which data is available (2007-8), accounts for 39 percent of global end of season wheat stocks, 30-33 percent of global coarse grain stocks, and 53 percent of global rice stocks. It is clear that, irrespective of whether the Chinese authorities use stocks for domestic market stabilization or for managing their net export/imports of basic food commodities, the size of Chinese stocks is likely to weigh heavily on any market analysis of these commodities, and on price expectations.

Turning now to the newer factors affecting market volatility, the most difficult to analyze is the influence of commodity traders in organized exchanges. The reason that this is very difficult is that the classification of traders as commercial (namely those who have an interest in the actual physical commodity), and non-commercial, that has been adopted in several large exchanges, and on the basis of which some data can be compiled, is not representative of the actual intentions and positions of financial funds, as well as other non-commercial actors (Gilbert, 2009). Data from participation of commercial and no-commercial traders in total open interest in the Chicago Board of Trade (CBOT) and in selected futures markets indicate that the share in open interest of non-commercial traders increased considerably in all CBOT markets between 2005-08, and this is the period of the financial boom. However, this simple contemporaneous development is not a proof of causality. The question is whether the undoubted increase in participation of non-commercial traders in the organized futures and other derivative markets, affected the market fundamentals, and in particular the level of prices and volatility. There is very little research on this issue, but some recent empirical analysis by Gilbert, 2009, and a policy brief by the Conference Board of Canada (CBS, 2008) seem to suggest that is price volatility that attracts non-commercial and other financial traders, and not the other way around.

A lot has been said about the influence of the unstable exchange rate of the US dollar on commodity markets. It is a fact that in recent years the USD exchange rate vas varied considerably against the currencies of other major trading countries. For instance the USD depreciated against the Euro by more than 30 percent between 2003 and 2007. It is also the case, albeit not obvious, that since the prices of most internationally traded agricultural commodities are quoted in USD, a USD depreciation has a considerable influence on USD prices of traded commodities. Figure 8 indicates that a one percent USD depreciation against all currencies, ceteris paribus, can have significant upwards influence on all agricultural commodity prices, and for some the relevant elasticity can be as high as 0.8-0.9 (this occurs mostly for livestock commodities, where developed countries are the major traders, and exchange rates most variable). Clearly then it appears that the instability of the USD exchange rates must have contributed significantly to market price volatility. Given recent global financial and production developments, the huge international financial flows they imply from agents looking for safe heavens, it is likely that this instability will continue in the future, and hence this is likely to continue affecting adversely commodity market volatilities.

Apart from the instability of the US dollar, macroeconomic instability is likely to have contributed considerably to commodity markets instability. Gilbert, 2009 in his empirical analysis finds that both money supply as well as GDP seem to Granger cause commodity prices. The influence maybe indirect, for instance through interest rates as Frankel (2008) has already indicated. The current financial crisis does not bode well for monetary stability, especially given the significant monetary expansion that is likely to follow the fiscal stimulus packages now envisioned in most large economies. Hence it is likely that macroeconomic factors will continue adding instability to world commodity markets.

The price of petroleum was already alluded to as an important determinant of agricultural commodity prices, especially for those commodities which can be utilized as biofuel production stock. Schmidhuber (2006) has shown that when petroleum prices are in a certain price range, then oil prices and biofuel stock prices seem to be much strongly correlated. This has been empirically substantiated by Balcombe and Rapsomanikis (2008) and for the sugar-oil-ethanol group. Several analysts have attributed significant influence on agricultural commodity prices from petroleum prices, coupled with biofuel policies (e.g. Mitchell, 2008, Abbott, *et al.* 2008). Despite the rapid fall of petroleum prices in late 2008 and early 2009, the underlying demand for oil in the medium term is real and likely to increase (OECD-FAO, 2008). This is likely to induce a continuing linkage between petroleum prices and biofuel stock prices, albeit not at all periods. As oil prices are likely to be quite unstable given the uncertainties in global economic growth, this most likely will induce instability of the agricultural commodity markets, both for those products that are directly related to biofuels, such as maize, sugar and rapeseed, but also in commodities that are substitutes in production.

The final factor that is likely to affect commodity market volatility is country policy actions and reactions to external events. The commodity scare of 2007-08 and the publicity it received made many governments overreact, by measures that were not always effective at achieving their stated objectives. A compilation from a FAO survey of government actions in 77 developing countries during the 2007-08 period revealed that there are only a few countries whose governments did nothing in response to the global commodity crisis. Perhaps surprisingly the region where few additional policies were adopted appears to be Africa. Secondly many developing countries intervened in trade by either reducing import tariffs or banning exports or other measures.

Given the size of the recent international price variations during a single year, (sharp increases in late 2007 and early 2008 and equally sharp price decreases in late 2008), many governments and market agents are rightfully questioning whether this type of extreme market volatility might continue in the future. In this context the following thoughts may be useful in assessing the future prospects for market volatility.

First, it will take some time for food stocks to be replenished, especially if unusual weather events continue to occur over the next few seasons. Despite the fact that prices have come down from their peaks of 2008, and that global production seems to have responded positively to the crisis, the decline in prices may discourage many farmers from further production increases, and governments from productive investments. Hence, stock replenishment may be a slow process, implying that the markets will be tightly balanced for some time to come. With the financial crisis hitting on top of the food crisis, financing will also be scarce for all investments, and this will include investments in stocks. Low interest rates will certainly not make this process any easier, as Frankel (2008) has argued.

Biofuel demand is likely to be important for some time, if petroleum prices stay high. With the global financial and now economic crisis lowering overall petroleum demand, this looks like a less pressing issue, but petroleum prices are highly uncertain, and hence it is not clear that they will come done strongly and persistently. Hence, biofuel demand is likely to stay strong, especially since mandates are likely to stay, and investments made in biofuel producing plants will not be easy to just abandon. Finally, biofuel demand is likely to stay until more energy efficient new generation biofuels that do not compete with land resources for food production become widely available commercially, and this is not likely to happen for several more years.

The final factor that is likely to affect commodity market volatility is country policy actions and reactions to external events. The commodity scare of 2007-8 and the publicity it received made many governments overreact, by measures that were not always effective at achieving their stated objectives. An FAO survey of government actions in 77 developing countries during the 2007-8 period tabulated the type of measures that were undertaken in response to the global price rises. It was revealed that there are only a few countries whose governments did nothing in response to the global commodity crisis. Perhaps surprisingly the region where few additional policies were adopted appears to be Africa. Nevertheless, discrete and largely unexpected policy responses, especially through marketing boards operations, increase uncertainty and weaken the incentive for the private sector to engage in trade. The presence and trading activities of both marketing boards and private firms give rise to a dual marketing system that often increases the fragility of the market. The lack of trust and the poor coordination between the public and the private sectors often result in food deficits and high domestic price volatility.

Based on the above considerations and current projections about world overall economic prospects, the medium term outlook for agricultural commodities is that the growth rate of world demand for agricultural food commodities will slow down in the next ten years but income sensitive products' demand will grow faster. Trade will grow faster than production as in the past. The growth in food demand will be larger in developing countries for all types of products. Supply is expected to keep up with moderate increases in productivity. Nevertheless new demands especially for biofuels are likely to keep prices firm in the medium term.

The overall conclusion then is that the global food commodity markets are likely to stay volatile in the next few years, until stocks are replenished, petroleum prices stabilize, and the global financial crisis works itself out. An added risk is that the efforts currently made to renew emphasis on agricultural investments to boost productive efficiency, especially in developing agriculture dependent countries, are derailed by the probably short lived hiatus of low global food commodity prices.

## 4. DEVELOPMENTS IN GLOBAL FOOD AND AGRICULTURAL SECTORS THAT WILL CONDITION FUTURE TRADE POLICIES

There are many events that are likely to shape future agricultural trade and trade policies. The past 30-35 years, namely the period since the mid 1970s and the last food crisis, have seen the emergence of a more globalized food system, and the policy concerns shifted to issues of growth in non-agriculture, and more open trade. The WTO and the debates surrounding agricultural trade have tended to neglect food security concerns. Nevertheless, the recent global food market events have refocused many policy makers' views back towards food security. Apart, however, from this there have been a series of developments that are likely to impinge considerably on global food markets and trade. A selection of these is listed below[1].

### 4.1 Uneven growth in the global economy

Almost all global projections suggest that growth in the next few decades, whether fast or slow will be faster in developing countries, and especially those of Asia. This will increase demand for the most income elastic food products, such as livestock products, fruits and vegetables. If most of the growth in many of the faster growing economies takes place outside agriculture, then the demand for imports will increase faster than overall demand. Concerns about how to satisfy this growing domestic demand for food is a major factor that will shape developing country agricultural trade policies, as well as their attitudes towards the WTO in the years to come. Similarly, fast growth in non-agricultural sectors may induce the familiar (from the now developed countries) political pressures to ease the adjustment via subsidies to rural areas. This will bring pressures for protection or domestic support. If the WTO constraints countries' freedom to apply relevant policies, then a conflict may arise between the WTO commitments and the domestic adjustment pressures. Hence some policy space may need to be left in WTO commitments of countries that are at different stages of development.

Perhaps more worrying for the world trade system as a whole is the prospect of a serious slowdown in global economic growth being accompanied by political tensions or trade disruptions. Of particular concern are oil supplies which depend on a small group of countries, many with potentially unstable regimes. Periods of inflation and slow growth in the past have been associated with sharp increases in the price of crude oil. While oil prices have eased recently after a sharp increase, most analysts predict that when the global economy exits from the current slowdown oils prices will increase again. Other types of disruptions, of the financial or real type are also not unlikely, and the issue is whether the global trade system as it has emerged over the period since the Kennedy Round can survive a serious downturn in the global economy that could lead to self-preservation policies that in effect destroy the mechanisms that have been laboriously established. Can the trade system as a whole and the agricultural trade rules survive a major 1930s type depression?

### 4.2 Growth in agricultural output and investment

The recent period of high food prices has brought to the attention of countries the extent to which investments are needed to maintain and increase the capacity of the agricultural sector to meet the demands of a growing population. Expenditure on research has been lagging in recent years, as a result of shifting priorities for public investment and lack of financial incentives for private investment. As was seen in Figures 2-4, the world prices for major agricultural food products have declined in the past four decades, but the trend appears to have slowed or stopped since 1980. Could this trend be due to a slowdown in global agricultural productivity? Figure 9 illustrates that yields of major agricultural food products have increased in developed and middle income developing countries but have stagnated in LDCs. It also illustrates the fact that yield levels are much smaller in LDCs compared to developed and middle income economies. As yield differences reflect largely larger application of modern inputs (better seeds, fertilizers and chemicals) it appears that there is considerable potential for bringing yield levels in developing countries to levels comparable to those of developed countries, but this necessitates considerable investments.

[1] The discussion in this section borrows several ideas from a paper written for FAO by Tim Josling (2008).

The possibilities for productivity improvements along with prospects for reasonable world prices for food commodities suggests the need for increases in public investment in the production of basic foodstuffs. Complementing this could be an increased interest in infrastructural improvements that are often the constraint on the marketing of local foods in developing countries. Public investment in agriculture however, may be hampered in a context of financial stringency.

On the other hand the role of the private sector will be crucial in keeping supply in line with demand. It is not clear that private investments will be forthcoming in the amounts necessary. There has been a recent resurgence of interest in international investment in agricultural land. Purchases of agricultural land in Africa by various Gulf States for food production have attracted most attention, although these are just one of a variety of actual or planned investment flows with different motivations. Investment companies in Europe and North America are also exploring opportunities motivated by potentially high expected returns on investment partly due to higher food prices and especially where biofuel feedstock production is a possibility.

The motivation for the recent spate of interest is food security and a fear arising from the recent high food prices and policy-induced supply shocks that dependence on world markets for foods supplies has become more risky. At the same time, a number of countries are making strenuous efforts to attract such investments to exploit "surplus" land. Benefits to the receiving country are a major concern. These should arise from capital inflows, technology transfer, employment creation, multiplier effects through local sourcing of labour and other inputs and possibly an increase in food supplies for the domestic market. However, foreign direct investment may create dependence on imported inputs and hence limited domestic multiplier effects.

Since the overall idea of this type of investments is to export the products produced, there are alternative business models for this, for instance contractual arrangements, as has been the pattern for the development of East African horticultural production for export by European supermarkets. It is also important to consider the various trade implications of any overt or hidden subsidies that accompany such arrangements.

### 4.3 Continued reform towards decoupled support in developed countries

The period since 1985 has seen a paradigm change in the management of the agricultural economy in both developed and developing economies, toward deregulation and the provision of incentives. The policy changes in developed countries in the 1980s have been from market intervention towards direct payments. In the EU this process accelerated over the 1990s as farm policy shifted to include environmental and quality aspects of food production, culminating in the reforms of 2003 that virtually eliminated for arable agriculture any link between farmer support payments and commodity market conditions. Progress in the United States of America has been less linear, with a move in 1996 to delink payments and production but some recidivism in 2002 and 2008 as commodity-based price support programs proved to have strong support in the farm lobby and in Congress.

In light of the new pressures and political demands coming from the recent food scare and the financial crisis, the issue for the next few decades is whether the reform process will continue towards agricultural policies that aim specifically at issues of productivity enhancement and risk management. Such a trend would be consistent with a more open trade system and the removal of the many impediments that developing countries face in supplying food to the industrial country markets. However, the pace of reforms could stall if the Doha negotiations are delayed or even abandoned.

### 4.4 Continued policy reform in developing countries

The more fundamental question is whether developing countries will follow the same pattern with respect to the protection of domestic markets and producers. Much of the impetus for public intervention in developed country agricultural markets came as a reaction to different patterns of adjustment of the agricultural and the non-agricultural sectors.

That the issue of appropriate trade policy at different levels of development needs to be addressed further is suggested by the fact that current protection levels by sector seem to be related to the stage of economic development. Tables 1, 2 and 3 exhibit a snapshot of some recent (circa 2001) data on the pattern of protection in agricultural, processed food, and non-agricultural non-food products, by developing and developed countries as represented by the ad-valorem equivalent. The major observation from these tables is that concerning agricultural products, the developing countries (except China and India) exhibit lower protection than most developed countries, especially the non-US and non-EU ones. Concerning processed foods, both developed and developing countries appear to have substantial but similar levels of protection, while for non-agriculture non-food products, protection in developing countries is generally higher than that of developed countries. LDCs in particular appear to have rather moderate levels of protection for both agricultural as well as non-agricultural products.

If the historical pattern of agricultural protection, as exhibited by the cross sectional evidence of the tables suggests that agriculture is first unprotected or even taxed at early stages of development, then goes through a cycle of protection and support during the period when the country achieves middle income, and finally it is liberalized, then attempts in WTO to bind current levels of protection and support may prevent some developing countries and LDCs from the flexibility needed to pass through the middle income phase of their development. It is not clear whether the rate of protection of agriculture will need to go through the historically traditional pattern in the now developing countries. However, if it does, and if the WTO new rules on agriculture do not allow it, then this may create pressures for other types of support that maybe deemed compatible with the WTO. Or in the worst case this may threaten the WTO itself. In order to prevent this it may be appropriate to allow for appropriate policy space for developing countries for the agricultural trade related policies.

### 4.5 Global volatility of prices and food security

This issue was already discussed above, and the result was that the world is likely to face increased uncertainty and likely volatility in agricultural trade. It is interesting to note in this context that the data in Figure 5 suggested that world price volatility has not changed significantly in the last forty years despite the fact that trade has been liberalized and world agriculture has become more globalized.

Price instability can undermine the legitimacy of the global market as a place in which countries can buy food supplies on a regular basis and make use of trade to supplement domestic production. The WTO rules are currently unbalanced: they spring into action when prices are low but do little to constrain government action when prices rise. So export subsidies are constrained and tariffs are bound, but export taxes are not limited and export embargoes barely mentioned. The ability of the world trade system to respond in times of price volatility is likely to be tested severely in the future, and some creative institutional arrangements may be needed.

### 4.6 Continued concern for environmental impacts of agriculture

One issue that was almost entirely absent from the discussion of agricultural policy in the 1960s was the impact of agriculture on the environment. Now it is rapidly becoming an important part of the equation when domestic and international farm policies are being decided. Agriculture emits about 14 percent of all greenhouse (GHGs) in the atmosphere but can also contribute to GHG reduction. The EU has to a large extent taken the lead on this issue by making farm support payments conditional on good environmental practices. But other countries are following down the path of recasting income support as compensation for environmental stewardship and the provision of public recreational goods. Other environmental issues (beside the biofuel subsidy issues) include the contribution of agriculture and forestry to carbon sequestration and the problems caused by methane emission by livestock.

The trade system is set up to recognize goods by their product attributes not by the process attributes that one needs to evaluate a carbon footprint. On the other hand once the concept of life-cycle analysis of products takes hold in national legislation the differentiation of goods by their method of production becomes inevitable. So until this disconnect can be resolved, one would expect increasing conflicts over the issue of the environmental impact of the production and processing methods of traded goods. Will this issue increase or decrease trade in foodstuffs? Increasing product differentiation is generally positive for trade. A variety of environment friendly biotechnologies may need to source materials from other countries with appropriate production conditions, hence making trade an important attribute of this new industry. However, more trade, especially of bulky products, may bring forth the issue of the environmental impact of transportation services. Policies to deal with the environment may include carbon taxes which may encourage local production at the expense of overseas supplies. The conclusion is that the rules on trade and environment will become more complicated.

### 4.7 Continued concentration and value chain development in the food system

Recent research has demonstrated that world trade in most products, and food products are no exception, is dominated by a few large multinational firms. While this has resulted in more diverse and cheaper food, as well as provided more consumer choice, especially in developed countries, a side effect is that corporate decisions can affect millions of farmers and consumers. Concern has grown that concentration of economic power could at some stage constrain rather than empower farmers and consumers.

Much trade in manufactures moves within the same firm, as supply chains lengthen. The same trend is noticeable in food trade. While within national borders many countries, especially developed ones, apply antimonopoly and antitrust laws, such rules and non-existent in international trade. Competition issues are part of the so-called Singapore issues that many countries deemed not desirable as part of the current Doha agenda. One of the main problems that hamper developments in this area is lack of appropriate data, as well as a legal vacuum. For instance, if a multinational company is monopolizing a market, which national or international authority should be responsible for disciplining it? Whether and when competition policy will re-emerge remains to be seen.

### 4.8 Consumer-driven food attributes and the rise of private standards[2]

The main manifestation of globalization of the food sector may have been the establishment of global supply chains: the driving force behind such chains has been supermarkets and food processors. The consumer has played a willing role in this development. In developed countries the successful attempt to package attributes of health and environmental responsibility with foodstuffs, along with animal welfare and in some cases labour conditions, has transformed the economics of food trade. In developing countries consumers have embraced the availability of non-local foods and the better reliability and quality control that can come with firm size and management expertise. Most of these tendencies have given rise to private standards that are additional or different than those that apply under the Sanitary and Phytosanitary (SPS) Agreement of the WTO, which tried to control the ability of governments to set import standards that were not justified by risk assessment and based on scientific evidence. The SPS Agreement itself has been useful, particularly in the area of animal and plant diseases, but has not been effective in the area of private standards.

The lack of jurisprudence over private standards coupled with their rapid flourishing has given rise to numerous issues in the global food sector. These issues can be grouped into two categories: legal issues that relate to the multilateral agreement construct of GATT, SPS, and TBT agreements and practical issues over the consequences of private standards, especially to developing countries, and the proposed solutions to solve or abate these consequences.

The legal issues address how GATT or the SPS and TBT agreements deal with private standards. What is the relationship between the SPS agreement and private standards? What is the applicability of the TBT agreement to private standards, particularly the Code of Good Practice? The answer to these questions depends on resolving certain definitional problems in the SPS and TBT agreements. The lack of jurisprudence makes answering these questions difficult. This in turn makes it difficult for national governments to determine whether private standards are a legitimate private-sector activity, with which governments should not interfere, or whether the SPS/TBT agreements obligate governments in importing countries to be responsible for private standards.

Especially problematic to the analysis is the blurring of the line between private and official standards. At what point does the interaction between a government body and a private-standard setting body render meaningless the distinction between “voluntary” private standards and official standards? What will be the result when a government standardizing body develops a national safety standard based on a privately-developed standard or when a Member permits entry of imported goods conditioned upon certification with a private standard that exceeds official requirements? These issues are not addressed in the WTO jurisprudence and are not readily answered by the SPS and TBT agreements.

Equally complicated is the issue of what legal consensus might be found. What would be the result if private standards were challenged under the WTO? What would be the implications of an attempt to expand the jurisdiction of the SPS and TBT agreements over private standards? Would these results and implications

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[2] The discussion in this subsection borrows from a paper written for FAO by Roberts (2009).

threaten the viability of the international food-trade system? In working towards a consensus, are there co-regulatory approaches under the WTO that can be used? Should regulatory space be specifically carved out for private standards? What should be the role of intergovernmental standard-setting bodies? Is the multilateral monitoring of private standards desirable and feasible? These issues are complex and not easily answered.

The most pressing practical issue that emerges from the employment of private standards in the global food supply is how do small producers cope with the costs of compliance? Are there alternatives to certification that could make a more practical and affordable model for small-scale producers while ensuring equivalent assurance outcomes? Can there be practical interpretation of standards to minimize unreasonable demands and opportunities for adding value? Is there a model that both addresses the specific needs of the retail supply chain and is practical and affordable for small-scale producers?

The question that countries will have to face is whether to try to amend the SPS Agreement to allow government regulations to respond to consumer concerns that have not been found to have scientific merit. In the absence of some sort of solution to this problem the SPS Agreement will increasingly become irrelevant for most food trade.

### 4.9 The proliferation of regional and bilateral agreements

Will the global food market begin to fragment as more regional and bilateral trade agreements are concluded? Or will these regional and bilateral effectively merge to create global free trade? The large countries or trading blocs such as the EU, United States of America, and Japan have already concluded many bilateral and regional trade agreements and more are under negotiation. Agriculture, if included at all, is usually included but in a careful manner not to upset the status quo and entails many exemptions.

There is an inherent asymmetry in such agreements, as the larger country with a larger market has an advantage over a smaller one. Preferential access to the larger market is usually bought at the cost of freer entry of the developed country partner's product in the market of the smaller country. However, a major obstacle to taking advantage of such agreements is adherence to the Rules of Origin (RoO), which can place undue cost and burden on many administratively weaker economies, with the consequence that the potential benefits from an agreement are not realized.

### 4.10 Growing water scarcity and increased food emergencies due to climatic shocks

Currently half a billion people live in countries chronically short of water. By 2050 the number will rise to more than four billion. As agriculture is the most significant user of water resources accounting for 69 percent of world fresh water use in 2000, it will be affected considerably. The growth of irrigation has contributed to increased agricultural productivity and production in the past, but under conditions of increasing water scarcity in many parts of the world (and especially according to the Inter-governmental Panel on Climate Change (IPCC) report on climate change in low income developing countries) this may not continue. Currently only 17 percent of the world's arable land is irrigated but that land produces over one third of the world's total food supply. Irrigation efficiency varies considerably by country and various subsidies and lack of appropriate pricing mechanisms tend to pervert incentives for efficient water use.

Also agricultural water needs change with changing diet patterns. While on average it takes about 2000 litres of water to produce the amount of food consumed by one person in one day (and this is about 500 times the amount of water drunk directly per person per day) this varies considerably depending on the type of food consumed. For instance one kg of rice grown in paddies requires about 1900 litres. But one kg of beef needs as much as 15 000 litres. The point is that changing incomes and diets coupled with changing water availabilities will lead to demands for more agricultural trade from regions that have abundant water resources towards those that have lesser such resources.

Growing water scarcity in several parts of the world due to climate change has been accompanied by increasing variability of production and attendant food emergencies. Figure 10 illustrates that the number of annual food emergencies and in particular those that are due to natural disasters has increased considerably over the past twenty years. This implies that food trade and in particular growing needs for emergency assistance will be another factor that will have to be taken into account by the global trading system.

## 5. FOOD DEPENDENCY AND FOOD INSECURITY AMONG LESS DEVELOPED ECONOMIES

Over the past 40 years, and despite significant developments in global trade, technology and aid, many developing countries but especially those in Africa have remained very dependent on agriculture. Table 4 indicates that both for Africa as a whole and for LDC Africa in particular the share of agriculture in GDP has decreased only slightly since 1970. During the same period, the share of economically active population employed in agriculture, while experiencing significant decline for Africa as a whole, from 76 percent in 1970 to 57 percent in 2002-4, in LDC Africa the share decreased from 83 percent to a still very high 71 percent. Despite this continuing dependence, Table 5 indicates that the shares of agricultural exports in total exports of merchandise as well as total exports of goods and services have declined to about half their shares in 1970.

This decline in agricultural export shares has been accompanied by growing agricultural imports. Table 6 indicates that during the same period, the share of agricultural imports in total imports of goods and services has declined, but the share of imports in total merchandise imports has increased, with the exception of North Africa. More significantly, the share of agricultural imports in total exports of goods and services, an index that can indicate the ability of the country to finance food imports, while declining from 1970 to 1980 and 1990, has increased considerably from 1990 to 2002-04. This suggests that agricultural (mostly food) imports have necessitated a large share of the export revenues of African countries.

Among Asian developing countries, by contrast, over the same time period the average share of agriculture in GDP has declined from 37 percent to 22 percent, the share of economically active population employed in agriculture has declined from 70 to 51 percent. The share of agricultural exports in total exports of goods and services has declined from 28.4 percent to 7.8 percent (as a share of merchandise exports the share of agriculture declined from 46.5 to 8.7 percent). The share of agricultural imports in total imports of goods and services has declined from 33.0 to 7.8 percent, and the share of total food imports in total exports of goods and services has declined from 15.5 to 7.1 percent. Hence Asian developing countries' food imports have not increased beyond their capacity to import them.

In Latin America and the Caribbean (LAC) by contrast agriculture as a share of GDP has increased on average in all regions (except Latin Caribbean) over the past 25 years (from 7.1 to 8.1 percent) while the share of economically active population in agriculture has declined from 34.5 to 18.6 percent. For most LAC countries exports of agricultural products constitute a large share of total merchandise exports (average about 35 percent), and agricultural imports are on average less than 20 percent of total merchandise imports. Hence the issue of growing food imports with inability to pay is mostly an African problem.

These developments have been accompanied by a decline in the income terms of trade for LDCs, which are largely African countries. Figure 11 indicates that during the period 1960-2002 the income terms of trade, as computed by the ratio of the value of agricultural exports to an index of import prices (the IMF Manufacturing Unit Value index), and which measures the purchasing power of agricultural exports, seems to have evolved totally differently for developed countries, LDCs and other (middle income) developing countries, with the index for the LDC showing a continuing decline, while that of the developed and other developing countries an increase. The basic reason for this development, since both groups of countries face the same international prices is the different rates of productivity growth as was illustrated in Figure 9. It is clear from that figure that in the last 20 years productivity increases have been strong in developed and other developing countries, while they have been very weak in LDCs.

Two other interesting structural developments are in order. The first concerns the fact that despite the fact that agricultural export dependence has declined for most developing countries, the high commodity dependence of agricultural exports has continued, especially for African countries. The second structural development concerns changes in the production structure of LDC agriculture. After 1980, almost all developing countries and most LDCs adopted stabilization and structural adjustment programs that intended in transforming their economic sectors towards more tradable commodities. This was particularly intended for agriculture, which had been characterized by many institutional and market rigidities and government monopolistic interventions. However, two decades after the onset of such programs the share of agricultural production that is accounted for by exportable and importable products does not appear to have changed very much. As Table 7 illustrates, the average share of the value of exportable production in the value of total agricultural production for 24 low income African countries in 2001-3 was estimated by the authors to be

21.8 percent compared to 23.1 percent in 1980-82. As for the share of import substitute products in total agricultural production over the same period, this seems to have stayed the same from 24.7 percent in 1980-82 to 25 percent in 2001-3.

Turning to medium term food outlook, we present some projections of net imports of the FAO COSIMO model that pertain to developing countries and LDCs. Figure 12 indicates that based on current estimates, developing countries will increase their net food imports by 2016 in all products except vegetable oils. Similarly Figure 13 indicates that LDCs are projected to become an increasing food deficit region in all products and increasingly so. Clearly this suggests that as LDCs become more dependent on international markets, they will become more exposed to international market instability.

The conclusion of this descriptive exposition is that many developing countries and especially LDC countries in Africa, have become more food import dependent, without becoming more productive in their own agricultural food producing sectors, or without expanding other export sectors to be able to counteract that import dependency. This implies that they may have become more exposed to international market instability and hence more vulnerable.

## 6. CONCLUSIONS AND OUTLOOK

The above discussion has illustrated various aspects of the world agricultural trade economy that may impinge on the future. Given population growth patterns and income projections, the largest challenge in the coming decades seems to be to ensure a global trading system that balances the objective of an orderly and dependable market for food with the objective of growth of many currently developing and least developed countries.

The conclusion of the discussion on volatility is that the global food commodity markets are likely to stay volatile in the next few years, until stocks are replenished, petroleum prices stabilize, and the global financial crisis works itself out. An added risk is that the efforts currently made to renew emphasis on agricultural investments to boost productive efficiency, especially in developing agriculture dependent countries, are derailed by the probably short lived hiatus of low global food commodity prices. This calls for continuing watch on global food markets and developments. In the medium and longer run, growing demand by emerging developing economies is likely to condition world food markets. Given that the conditions for agricultural production are likely to stay favorable (from a technological and ecological perspective) with the more developed and some middle income countries, the future seems likely to produce more trade and especially more north-south trade in agricultural products.

At the same time the food security considerations of many developing but also some developed and oil rich countries that cannot produce the food they need, may induce considerable reordering of the pattern of ownership of production. Significant developments that need to be monitored are on the one hand the tendency of some food dependent economies towards a higher degree of self sufficiency, and at the same time tendencies of some richer food importing countries to negotiate agreements for food production and committed export to their own countries. The institutional context within which these developments will take place and the public-private or state-state types of partnerships and arrangements that will evolve may necessitate a reconsideration of some world trading rules.

Similarly the major structural change in the global food markets is the emergence of the large food multinationals as well as the dominance of supermarkets. The types of international regulatory framework needed to accommodate the challenges and risks of this development have not been considered much until now and will surely pose challenges for the future trading system.

Finally and not least, the global trading system must accommodate rules that can ensure a more stable and reliable food trade. Lack of food creates considerable insecurities across the world and may lead to perverse policies and outcomes. The recent events demonstrated that a more liberal agrifood trading system is not necessarily more stable. It is conceivable that more stability may need more long term contractual arrangements on a country-country or even country-private nature. Regional or bilateral arrangements may create more stability but the trading system may need to ensure that this is not at the expense of more instability of those that are left outside such arrangements. The plight of developing countries must be particularly born in mind. To that end development needs to be a continuing and integral part of the WTO and not one of passing convenience.

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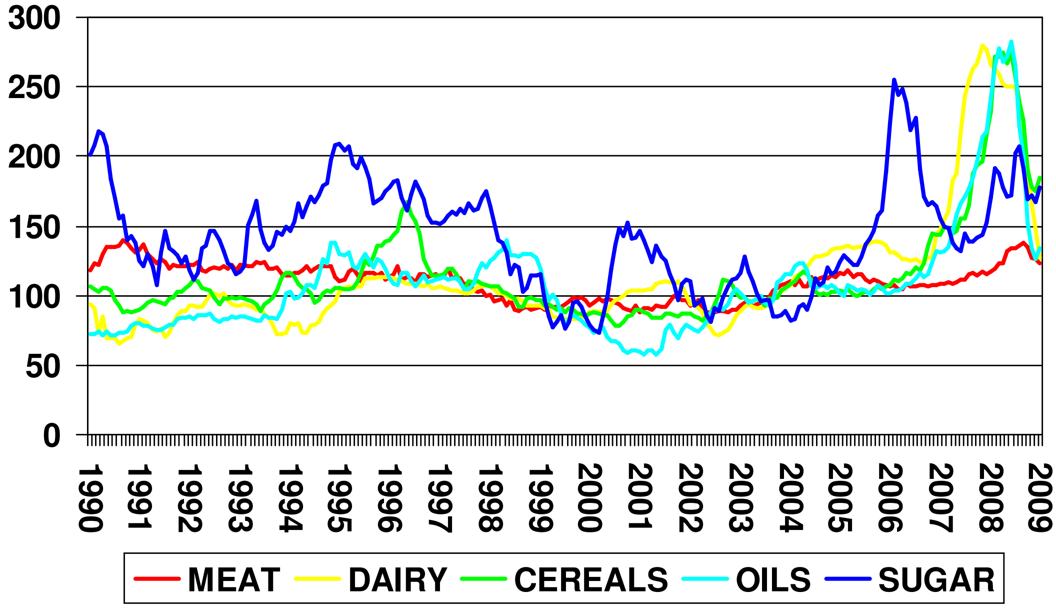
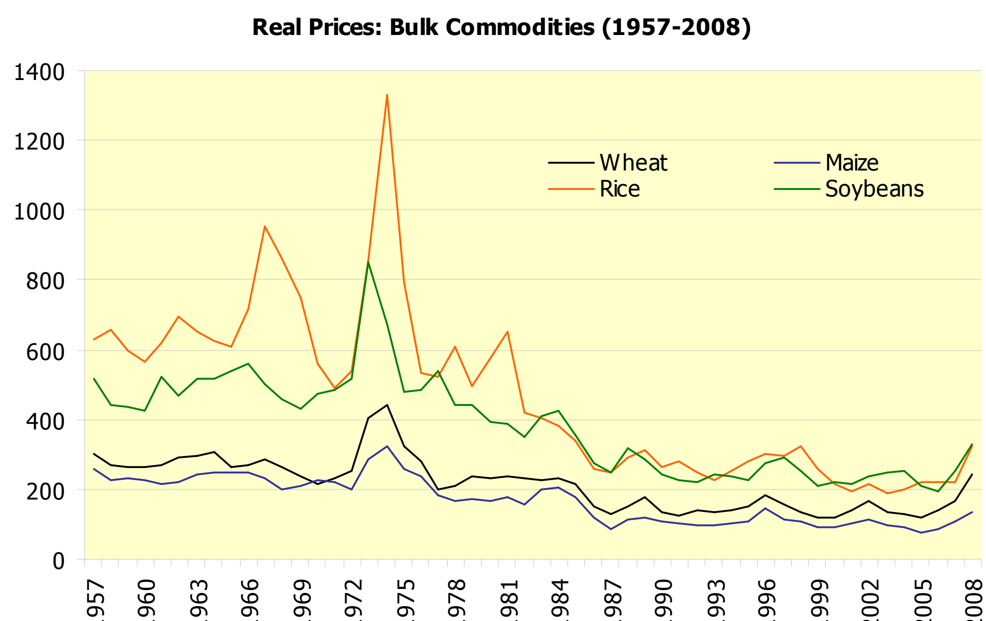
**Figure 1 Recent basic food commodity international price indices (1998-2000=100)**



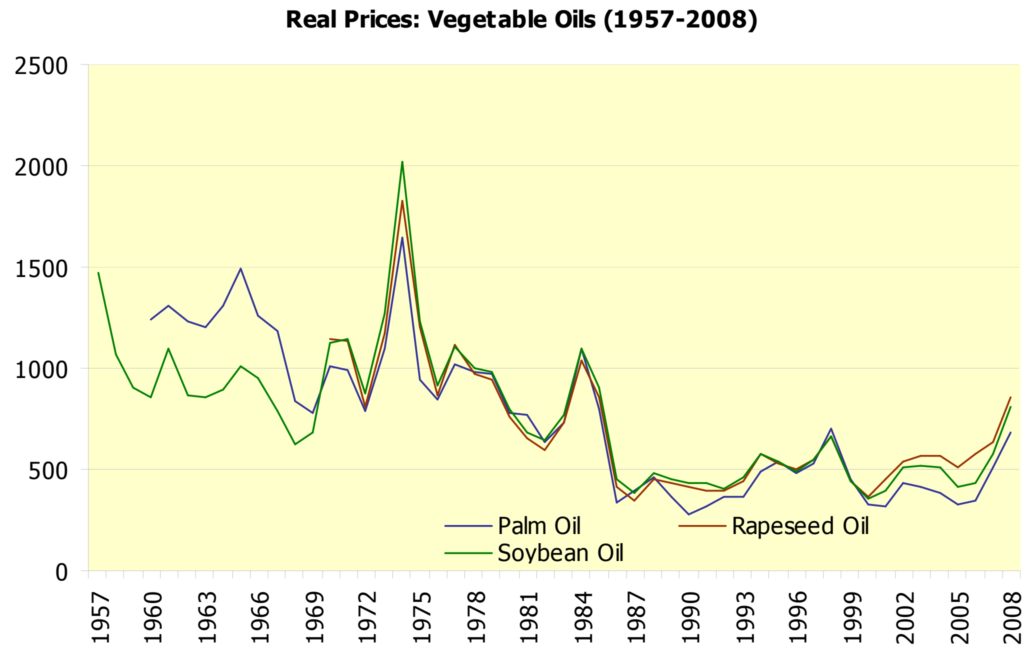

Source: FAO

**Figure 2 Real prices of bulk food commodities 1957-2008**



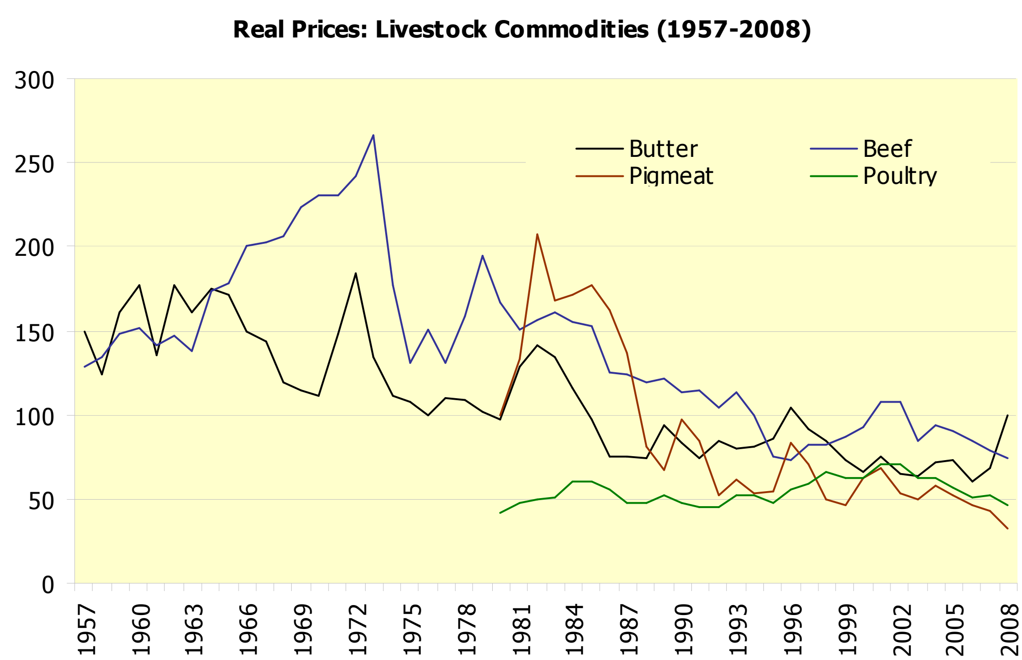

Source: FAO Trade and Markets Division

**Figure 3 Real prices of vegetable oils 1957-2008**




Source: FAO Trade and Markets Division

**Figure 4 Real prices of livestock commodities 1957-2008**




Source: FAO Trade and Markets Division

**Figure 5 Historic volatility and nominal international price for the major food commodities**

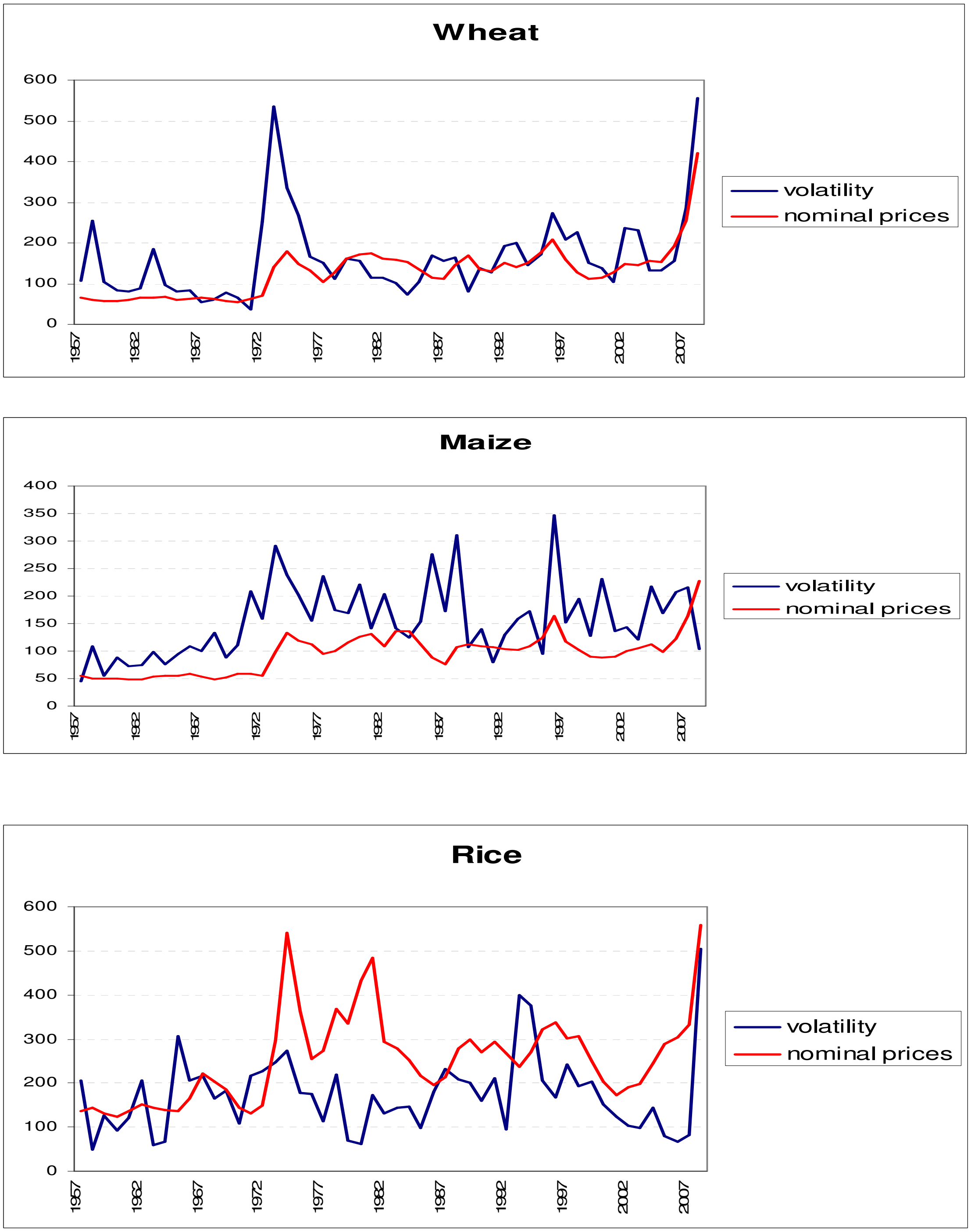
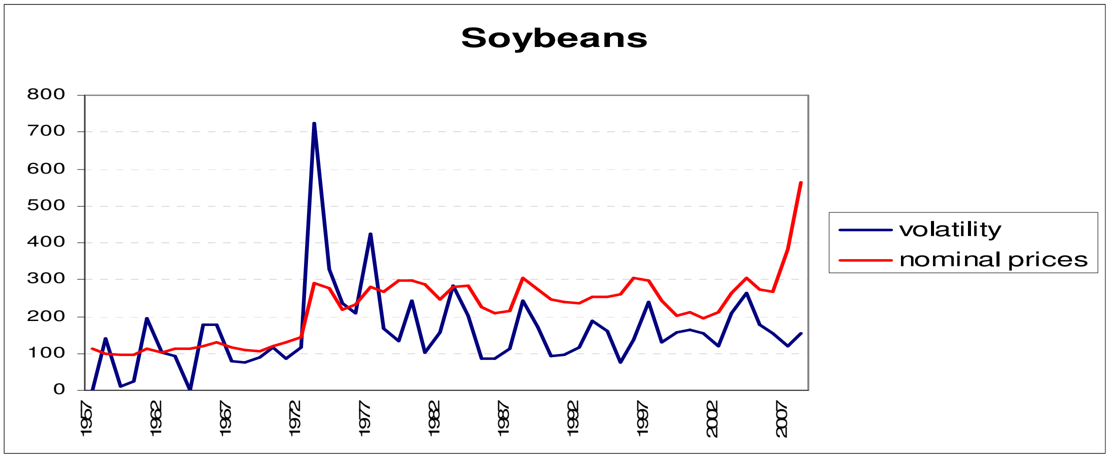
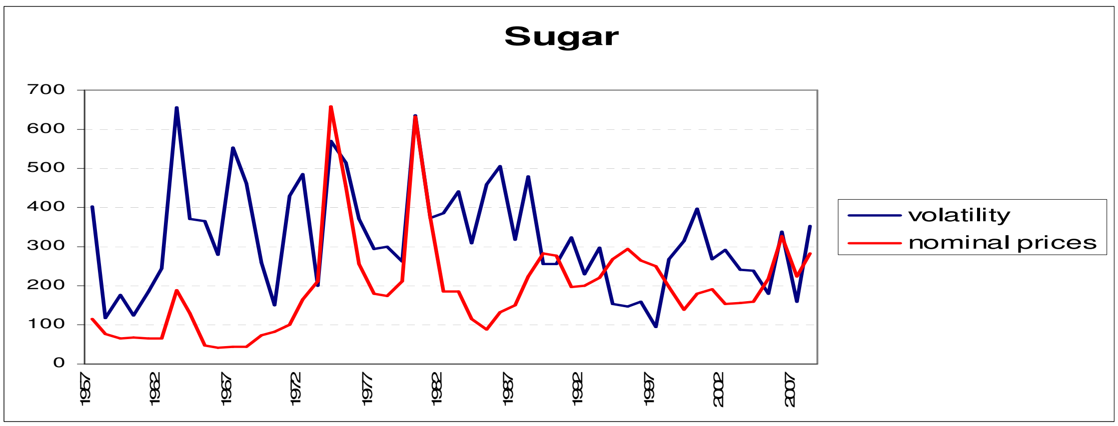
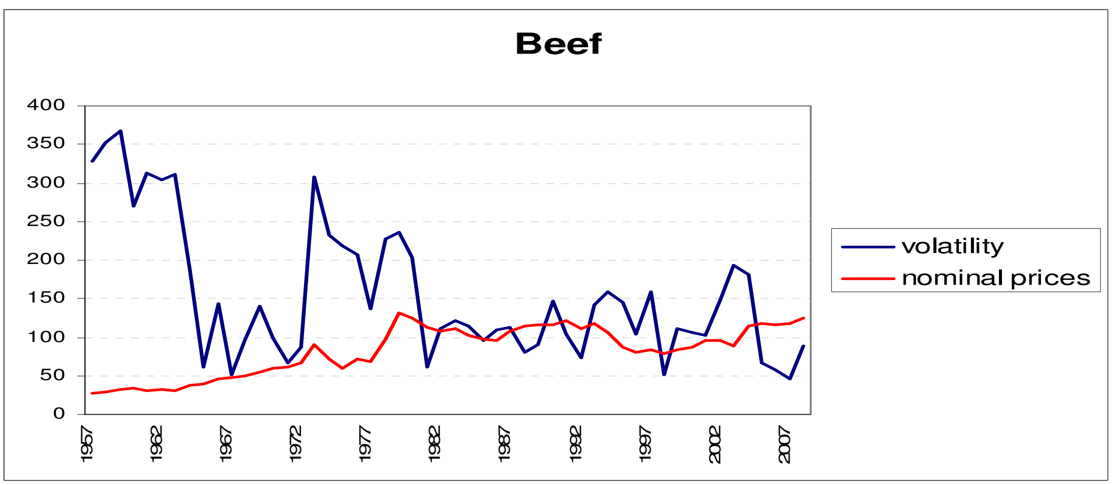


**Figure 5 (continued)**

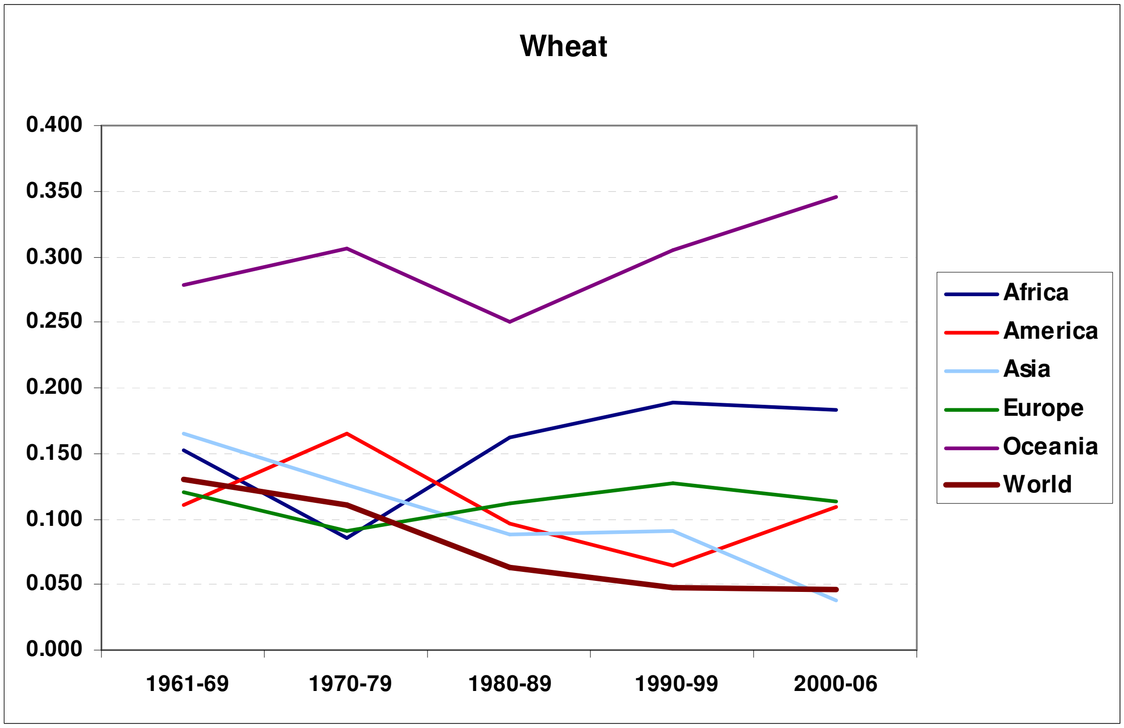



Source: FAO Trade and Markets Division and author's calculations

**Figure 6: Coefficients of variation of regional and global production of major food commodities since 1961.**



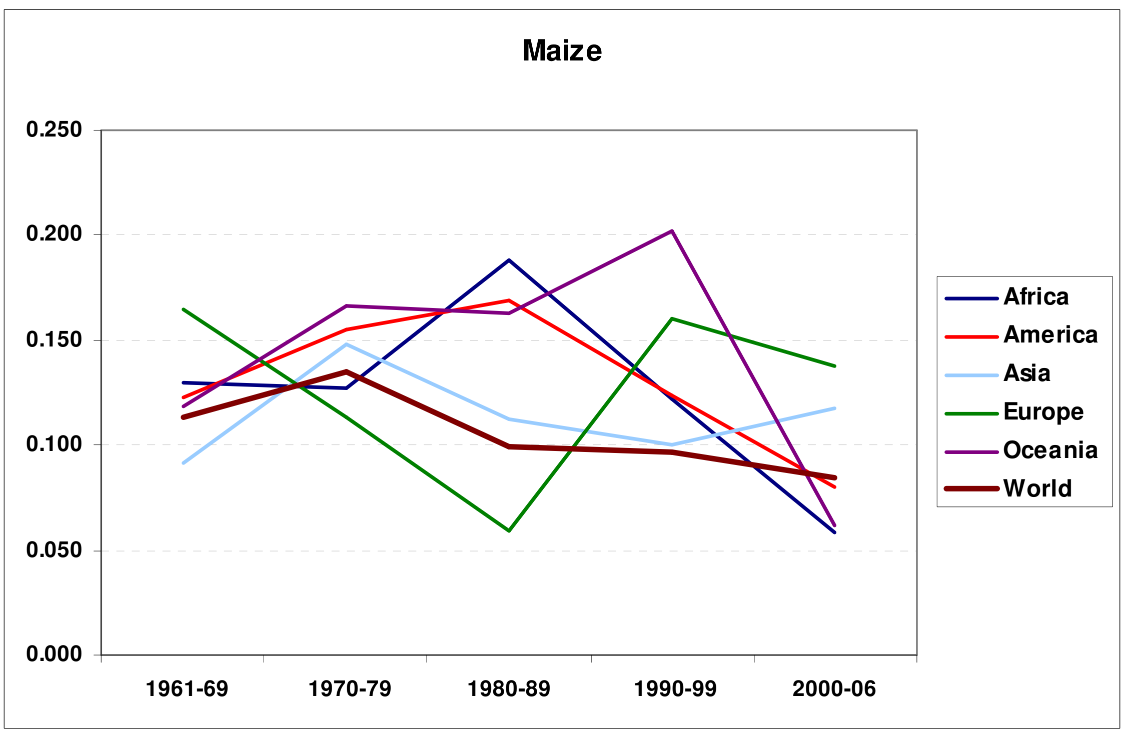
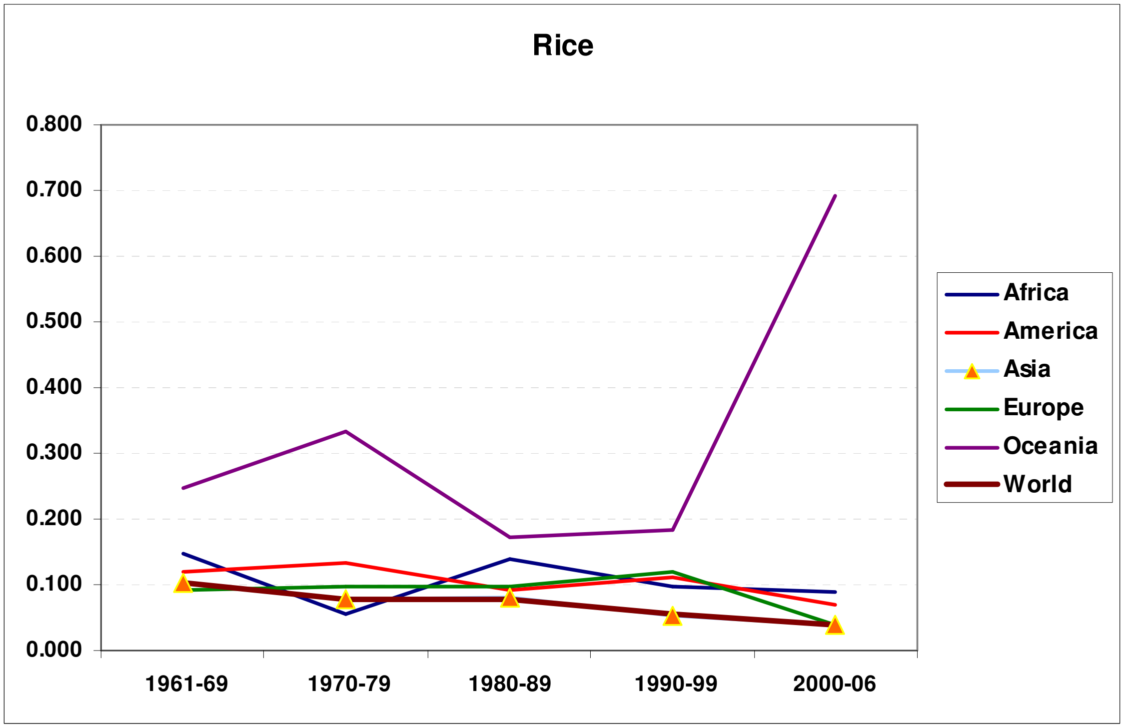
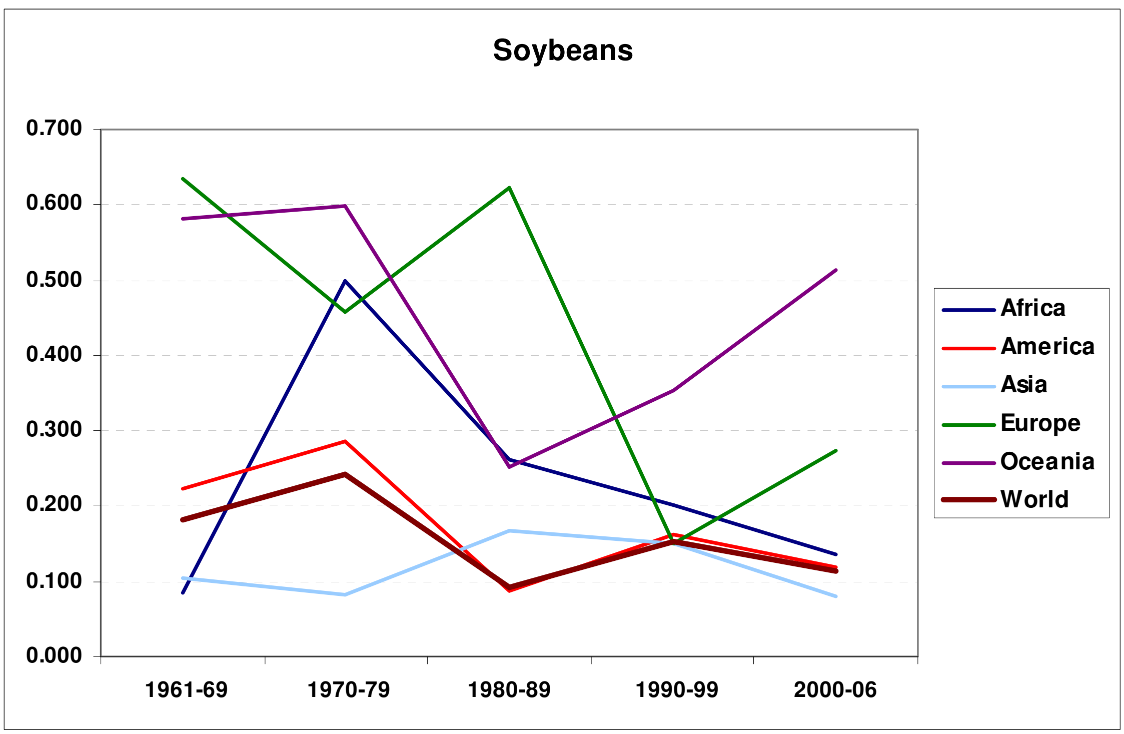



**Figure 6 (continued)**

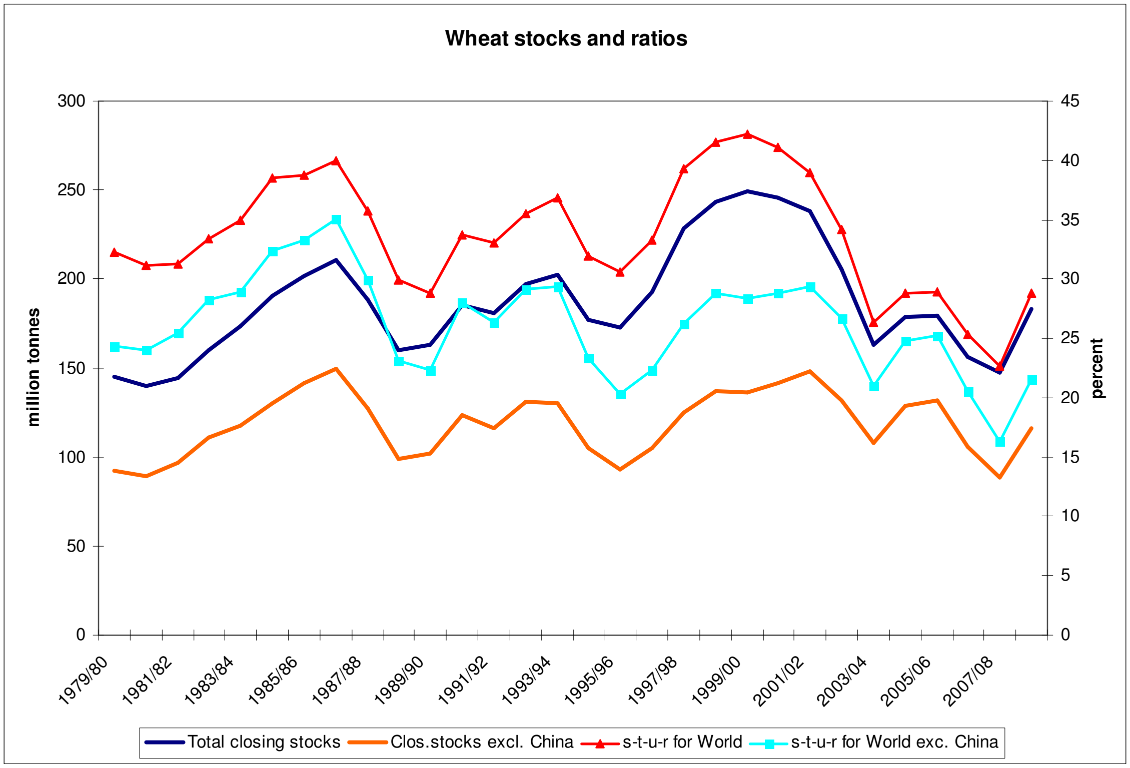



Source: Computed from FAO data

**Figure 7: Global ending stocks of major cereals and stock to utilization ratios for the whole world and for the world without China**

A. **Wheat**




**B. Maize**

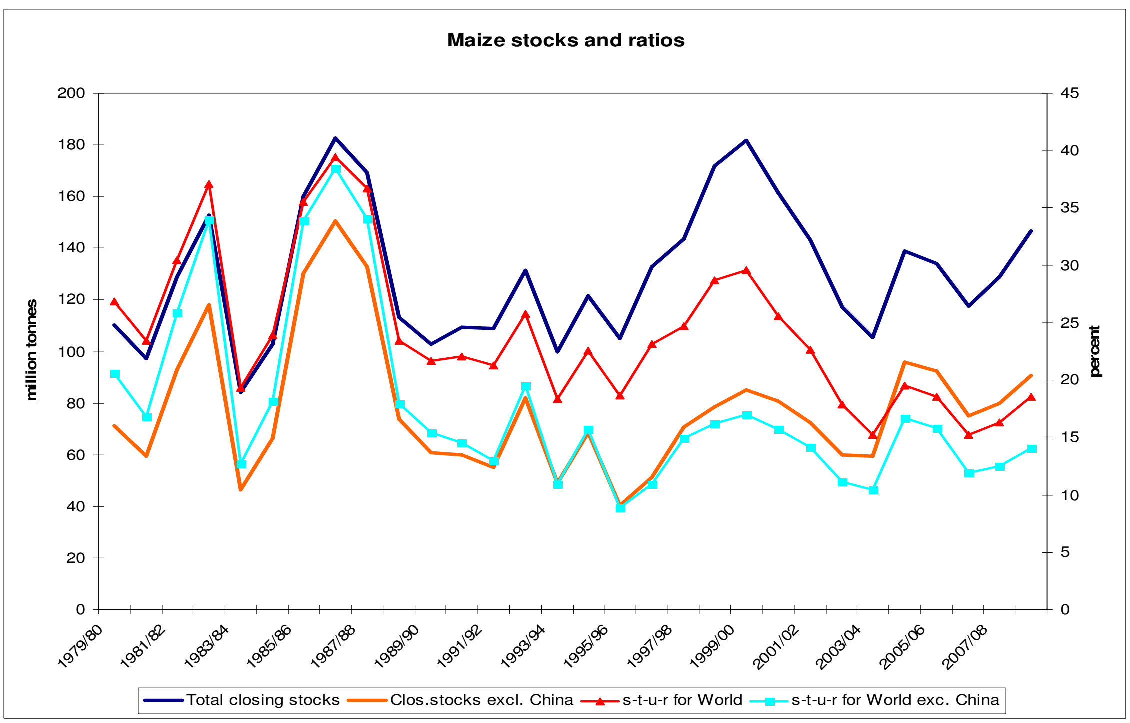
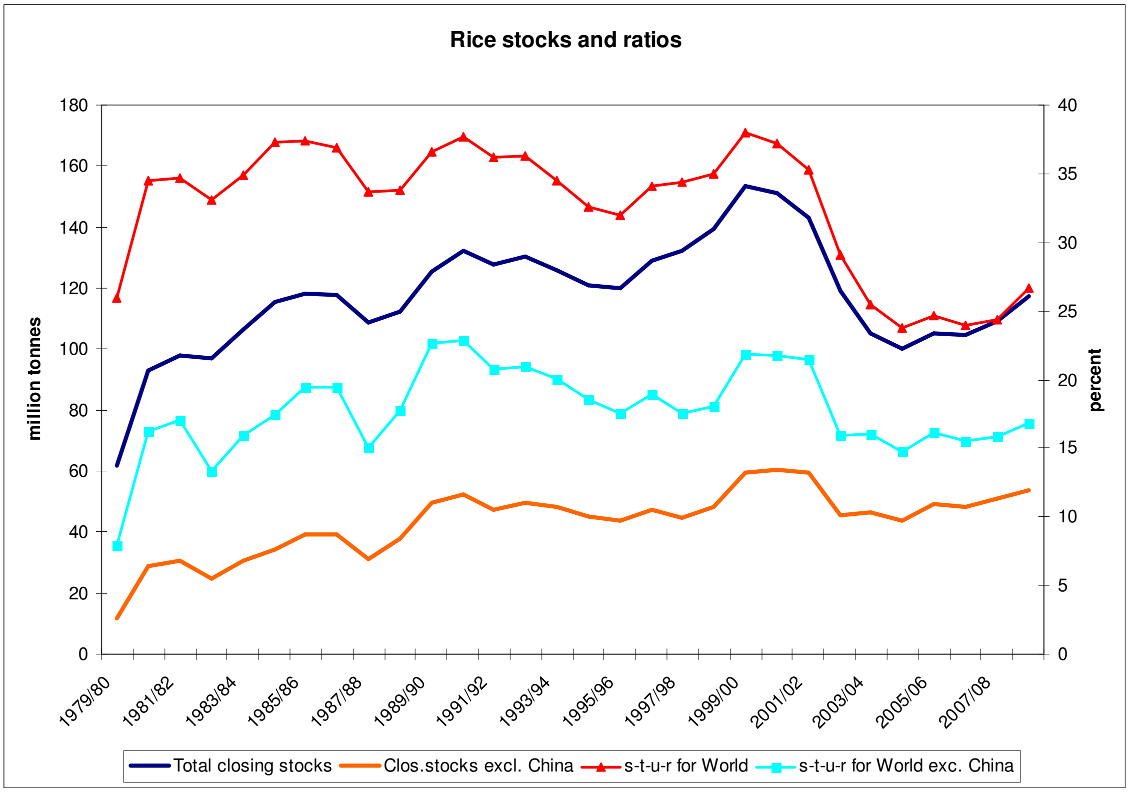
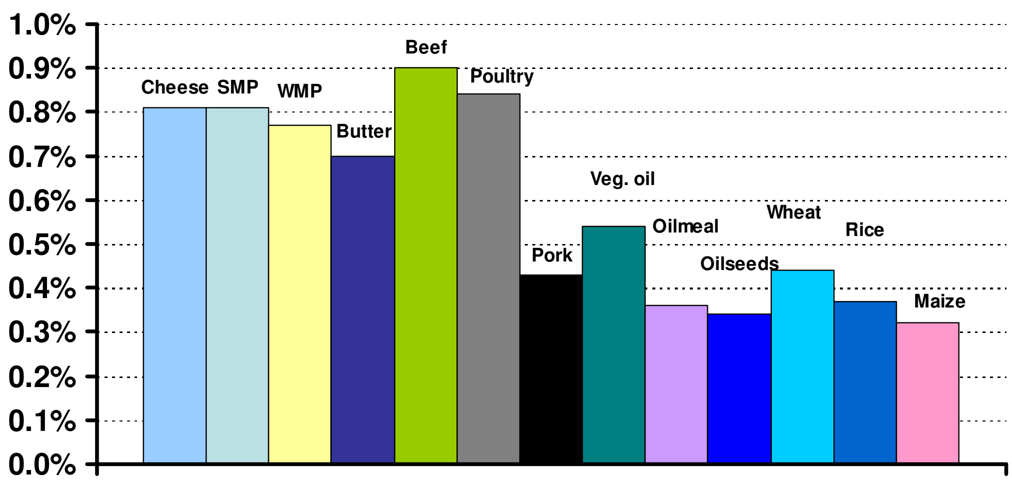


**Figure 7 (continued)**




Source: FAO Trade and Markets Division

**Figure 8 Impact of a one percent USD depreciation against all currencies on world agricultural commodity prices.**




Source. FAO Trade and Markets Division

**Figure 9: Average yields in developed, LDC and other developing countries, 1985-2004**

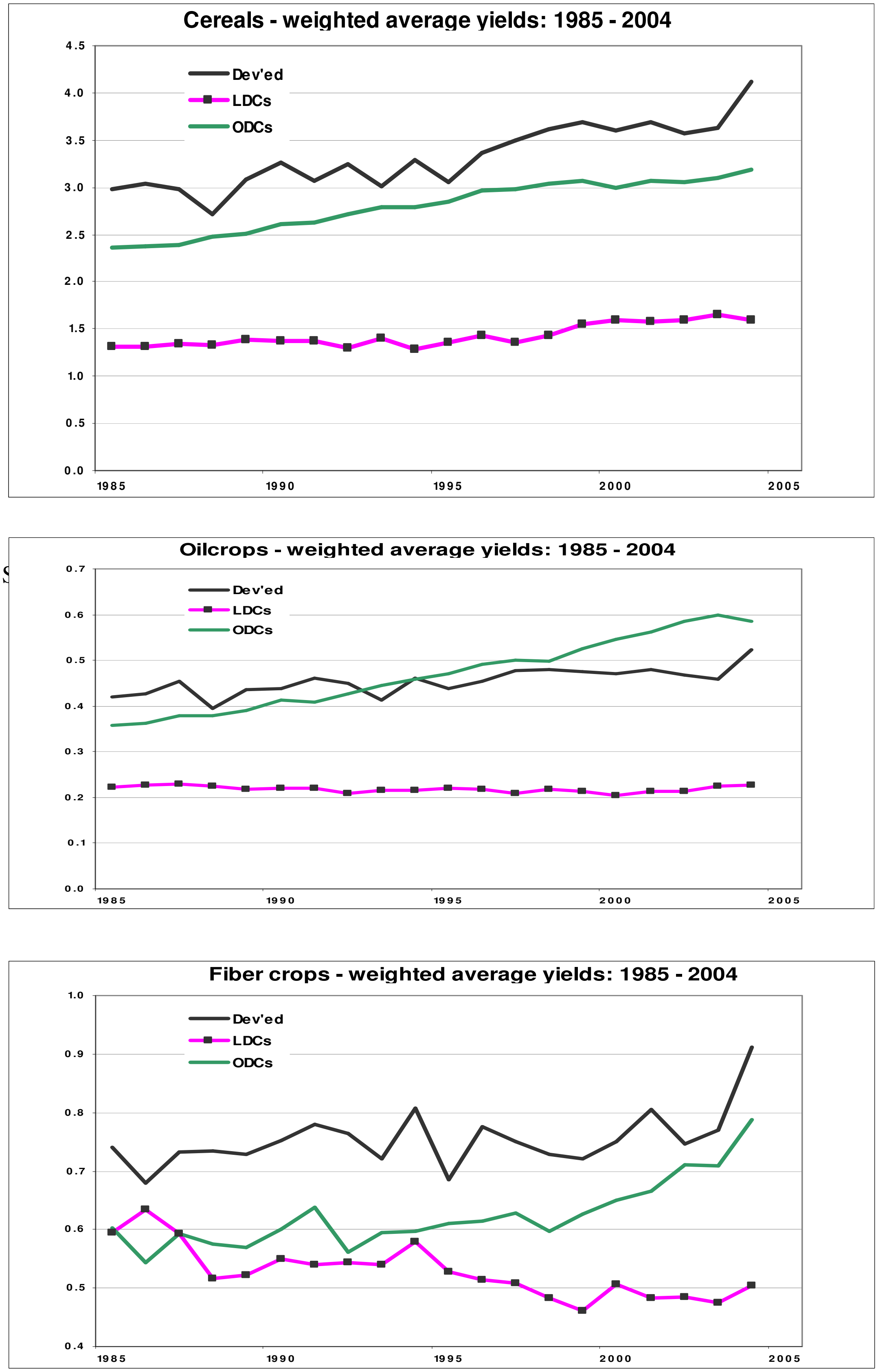
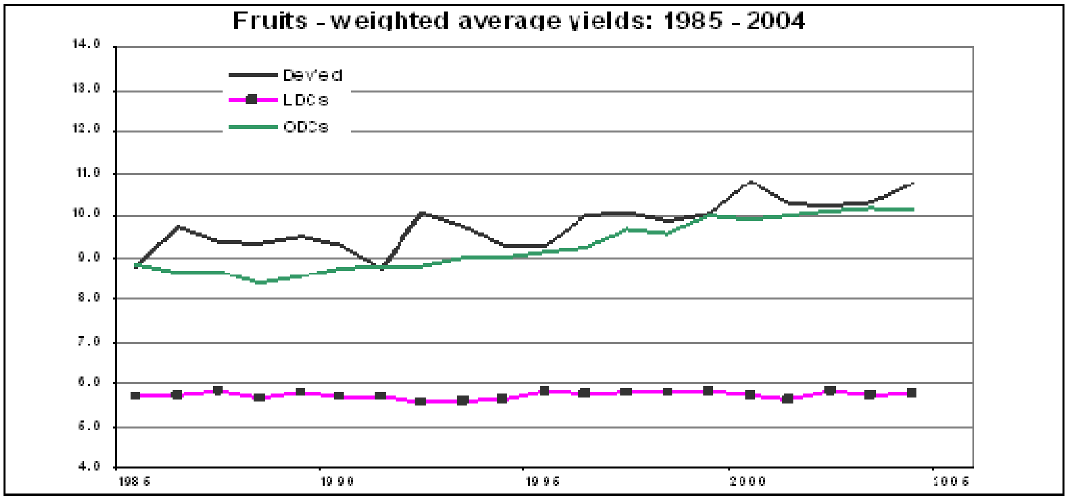
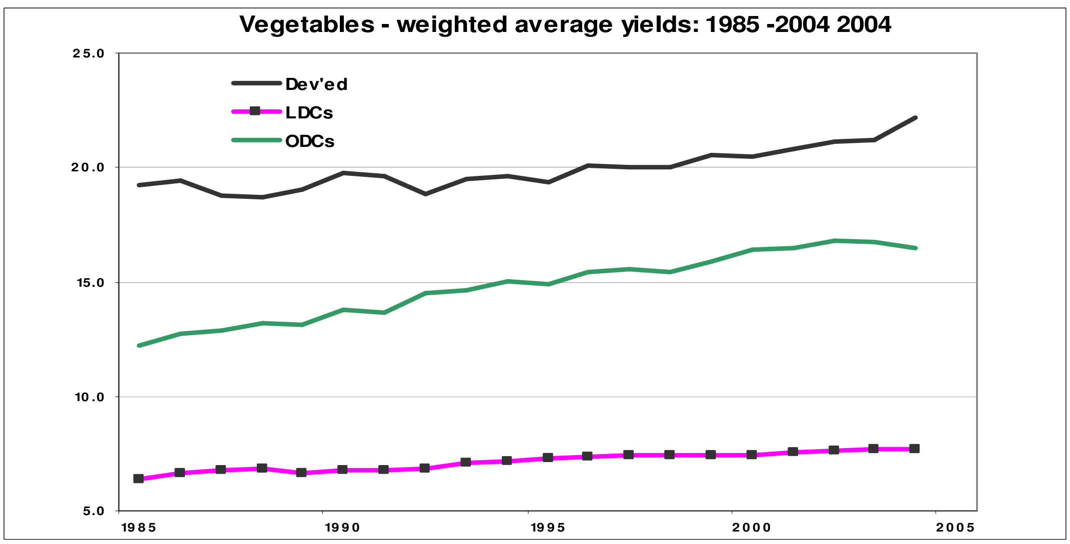


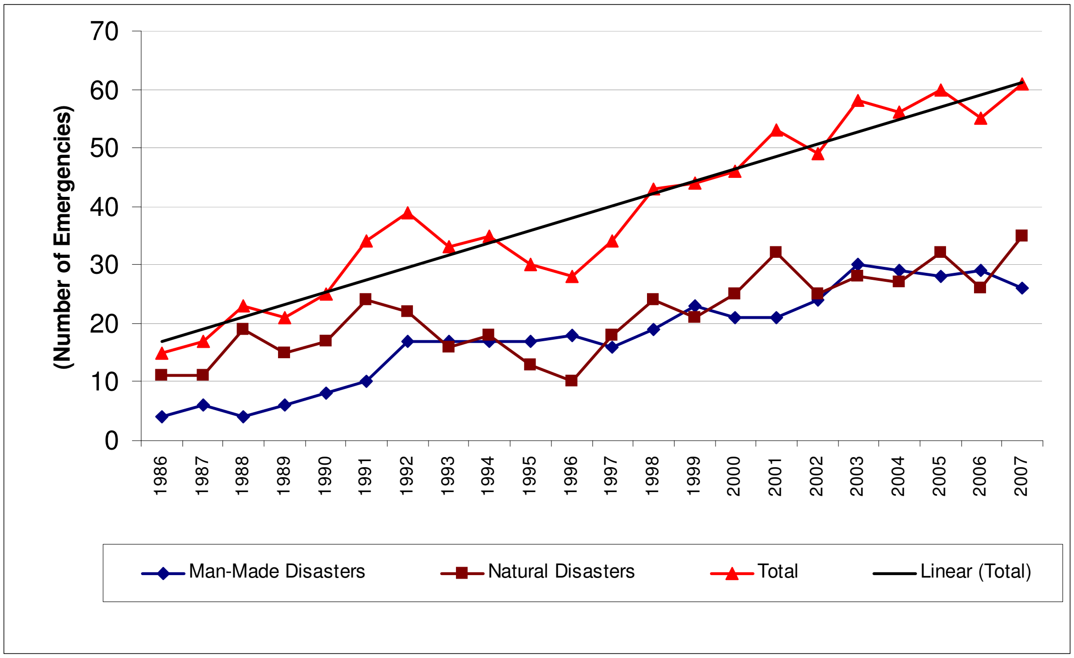
**Figure 9 (continued)**



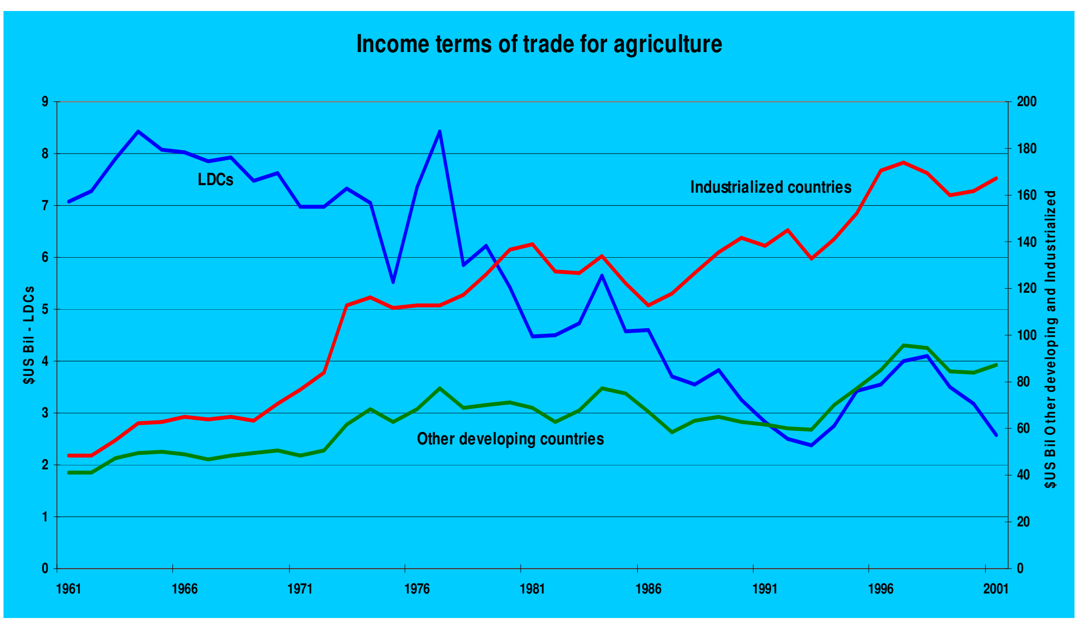

Source: Author's calculations from FAO data

**Figure 10: Trends and causes of food emergencies**



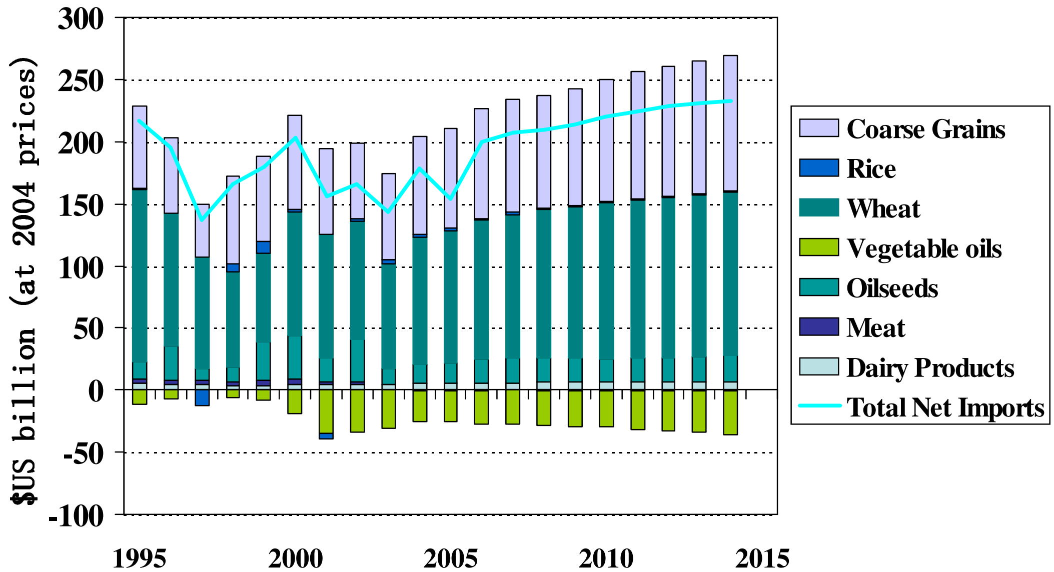

Source: FAO Global Information and Early Warning System (GIEWS)

**Figure 11: Income terms of trade for agriculture have deteriorated for LDCs during the last 40 years.**



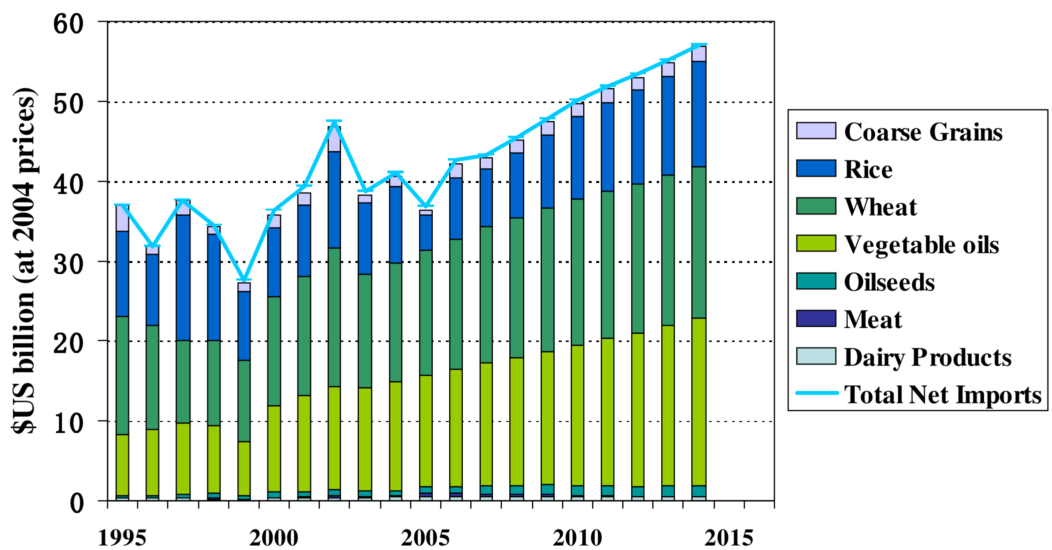

Source: FAO, State of Agricultural Commodity Markets 2004

**Figure 12 Net imports of agricultural products by developing countries**




Source: FAO Trade and Markets Division

**Figure 13 Net imports of agricultural products by LDCs**




Source: FAO Trade and Markets Division

**Table 1 Average ad-valorem tariff equivalent in 2001 of imports of all agricultural products by country in column from exporting country in row**

| | USA | BRAZIL | EU25 | CHI-IND | ROECD | LDCs | ODCs | ROW |
|---|---|---|---|---|---|---|---|---|
| USA | 0.0 | 5.9 | 5.1 | 62.2 | 36.3 | 7.3 | 8.9 | 11.1 |
| BRAZIL | 5.6 | 0.0 | 3.5 | 95.8 | 99.3 | 8.5 | 9.8 | 29.7 |
| EU25 | 1.8 | 7.3 | 0.9 | 22.1 | 16.3 | 9.5 | 12.8 | 16.3 |
| CHI-IND | 1.1 | 8.7 | 12.7 | 20.0 | 86.8 | 11.8 | 6.8 | 7.9 |
| ROECD | 0.2 | 5.5 | 3.2 | 20.3 | 32.1 | 8.2 | 5.5 | 11.2 |
| LDCs | 2.5 | 10.1 | 3.0 | 26.7 | 32.3 | 8.7 | 6.3 | 5.9 |
| ODCs | 1.4 | 1.5 | 12.3 | 53.4 | 20.1 | 10.3 | 9.1 | 16.7 |
| ROW | 6.3 | 10.3 | 2.9 | 14.6 | 10.0 | 3.0 | 16.3 | 4.5 |

Source: Morrison and Sarris (2006) based on GTAP database version 6 (Dec. 2004) In the tables ODCs refers to other developing countries, except Brazil, China, India and the LDCs

**Table 2 Average ad-valorem tariff equivalent in 2001 of imports of all processed food products by country in column from exporting country in row**

| | USA | BRAZIL | EU25 | CHI-IND | ROECD | LDCs | ODCs | ROW |
|---|---|---|---|---|---|---|---|---|
| USA | 0.0 | 14.7 | 16.4 | 22.2 | 23.7 | 19.6 | 20.4 | 21.8 |
| BRAZIL | 8.9 | 0.0 | 34.4 | 37.2 | 21.3 | 19.1 | 9.1 | 25.5 |
| EU25 | 3.8 | 16.4 | 1.3 | 30.7 | 27.6 | 25.6 | 16.5 | 19.7 |
| CHI-IND | 2.6 | 12.2 | 19.9 | 18.3 | 23.7 | 23.3 | 10.3 | 19.1 |
| ROECD | 2.3 | 16.5 | 14.2 | 20.4 | 35.2 | 20.3 | 14.0 | 21.9 |
| LDCs | 2.4 | 9.5 | 13.4 | 20.8 | 5.2 | 13.6 | 12.7 | 7.8 |
| ODCs | 3.9 | 3.1 | 18.6 | 44.8 | 18.7 | 26.6 | 12.8 | 26.2 |
| ROW | 2.5 | 5.8 | 9.8 | 17.0 | 9.0 | 15.2 | 21.6 | 6.3 |

Source: Morrison and Sarris (2006) based on GTAP database version 6 (Dec. 2004)

**Table 3 Average ad-valorem tariff equivalent in 2001 of imports of non-food secondary and non-agricultural primary products by country in column from exporting country in row**

| | USA | BRAZIL | EU25 | CHI-IND | ROECD | LDCs | ODCs | ROW |
|---|---|---|---|---|---|---|---|---|
| USA | 0.0 | 9.9 | 1.9 | 12.3 | 1.1 | 12.2 | 5.0 | 3.7 |
| BRAZIL | 2.1 | 0.0 | 1.4 | 9.4 | 6.6 | 21.3 | 6.2 | 3.3 |
| EU25 | 1.9 | 11.9 | 0.2 | 17.4 | 3.0 | 14.1 | 7.5 | 4.5 |
| CHI-IND | 3.8 | 11.5 | 3.6 | 19.4 | 5.0 | 19.5 | 6.3 | 12.0 |
| ROECD | 0.7 | 12.9 | 2.3 | 14.1 | 3.9 | 17.2 | 6.1 | 4.3 |
| LDCs | 3.2 | 0.3 | 0.3 | 4.5 | 2.6 | 6.9 | 2.7 | 3.9 |
| ODCs | 2.8 | 6.9 | 1.6 | 13.7 | 2.3 | 15.2 | 4.0 | 3.9 |
| ROW | 2.1 | 6.1 | 0.9 | 8.1 | 2.1 | 14.0 | 7.1 | 1.5 |

Source: Morrison and Sarris (2006) based on GTAP database version 6 (Dec. 2004)

**Table 4 Africa and dependence on agriculture**

| Share of Agriculture in GDP | | | | |
|---|---|---|---|---|
| | 1969-71 | 1979-81 | 1989-91 | 2002-04 |
| **North Africa** | 19.1 | 14.7 | 16.0 | 13.6 |
| **Sub-Saharan Africa: LDC** | 40.2 | 40.4 | 37.5 | 38.8 |
| **Sub-Saharan Africa: Other** | 30.6 | 27.6 | 27.1 | 26.6 |
| **Africa** | 31.9 | 29.6 | 28.7 | 28.4 |
| **Share of economically active population in agriculture in total economically active population** | | | | |
| | 1969-71 | 1979-81 | 1989-91 | 2002-04 |
| **North Africa** | 0.54 | 0.43 | 0.30 | 0.23 |
| **Sub-Saharan Africa: LDC** | 0.83 | 0.79 | 0.76 | 0.71 |
| **Sub-Saharan Africa: Other** | 0.68 | 0.60 | 0.49 | 0.41 |
| **Africa** | 0.76 | 0.70 | 0.63 | 0.57 |

Source: Authors' calculations from FAO data

**Table 5 Africa and agricultural exports**

| Share of agricultural exports in total exports of goods and services | | | | |
|---|---|---|---|---|
| | 1969-71 | 1979-81 | 1989-91 | 2002-04 |
| **North Africa** | 24.5 | 7.3 | 4.2 | 3.7 |
| **Sub-Saharan Africa: LDC** | 65.5 | 43.4 | 38.6 | 32.4 |
| **Sub-Saharan Africa: Other** | 37.4 | 25.5 | 20.7 | 23.5 |
| **Africa** | 46.8 | 29.6 | 25.1 | 23.4 |
| **Share of agricultural exports in total merchandise exports** | | | | |
| | 1969-71 | 1979-81 | 1989-91 | 2002-04 |
| **North Africa** | 33.4 | 11.8 | 8.3 | 6.0 |
| **Sub-Saharan Africa: LDC** | 65.6 | 54.4 | 46.0 | 32.5 |
| **Sub-Saharan Africa: Other** | 52.1 | 34.2 | 26.2 | 19.3 |
| **Africa** | 58.8 | 44.7 | 36.9 | 26.3 |

Source: Authors' calculations from FAO data

**Table 6 Developments in African agricultural import dependence 1970-2004**

| Share of agricultural imports in total imports of goods and services | | | | |
|---|---|---|---|---|
| | 1969-71 | 1979-81 | 1989-91 | 2002-04 |
| **North Africa** | 20.4 | 4.8 | 3.5 | 3.4 |
| **Sub-Saharan Africa: LDC** | 38.4 | 22.2 | 19.6 | 15.1 |
| **Sub-Saharan Africa: Other** | 33.5 | 20.9 | 21.4 | 15.9 |
| **Africa** | 33.3 | 18.5 | 17.3 | 13.2 |
| **Share of agricultural imports in total merchandise imports** | | | | |
| | 1969-71 | 1979-81 | 1989-91 | 2002-04 |
| **North Africa** | 23.9 | 24.2 | 23.0 | 17.5 |
| **Sub-Saharan Africa: LDC** | 21.5 | 22.2 | 25.9 | 27.3 |
| **Sub-Saharan Africa: Other** | 17.4 | 14.8 | 14.2 | 18.1 |
| **Africa** | 20.6 | 20.3 | 22.4 | 23.7 |
| **Share of food imports in total exports of goods and services** | | | | |
| | 1969-71 | 1979-81 | 1989-91 | 2002-04 |
| **North Africa** | 14.4 | 18.3 | 13.2 | 9.9 |
| **Sub-Saharan Africa: LDC** | 37.6 | 28.2 | 30.2 | 34.9 |
| **Sub-Saharan Africa: Other** | 14.1 | 8.7 | 6.8 | 11.1 |
| **Africa** | 24.1 | 18.8 | 17.9 | 20.9 |

Source:Authors'calculations from FAO data

**Table 7 Evolving production structure in commodity dependent developing countries**

| | Ratio of the value of production of exportables to the total value of agricultural production (percent) | | | Ratio of the value of production of importables to the total value of agricultural production (percent) | | |
|---|---|---|---|---|---|---|
| | 1980-82 | 1989-91 | 2001-03 | 1980-82 | 1989-91 | 2001-03 |
| Africa (24 ctries) | 23.1 | 22.1 | 21.8 | 24.7 | 25.7 | 25.0 |
| Latin Am. Carib (11 ctries | 48.1 | 52.8 | 48.0 | 45.0 | 43.8 | 41.8 |
| Oceania (3 ctries) | 45.8 | 39.3 | 37.1 | 8.4 | 9.5 | 12.6 |

Source: Authors'calculations from FAO data

# FARM SUPPORT POLICIES THAT MINIMIZE GLOBAL DISTORTIONARY EFFECTS

**Aziz Elbehri and Alexander Sarris***

## INTRODUCTION

The recent world food crisis highlighted the critical issue of global food security and the need to enhance global agricultural production capacity to meet current and future food demand. Increased investment in agriculture and adequate incentives to farmers are required to meet this global challenge. A key question is how to shape and design support to farmers in both the developed as well as the developing world while minimizing those distortions to global markets that are potentially harmful to developing countries, and at the same time promoting global food supply adequacy, food security for the undernourished, and poverty reducing and growth incentives for the farmers in low income food deficit countries.

Developed countries provide support to farmers to increase farm income, reduce income variability, improve competitiveness of the agricultural sector, and provide for safe (in terms of production processes and health) and quality food. Recently other functions of agriculture, such as environmental services, have provided additional impetus for farm support. Many farm support policies stimulate domestic production, but also create distortions in world markets, inducing disincentives in developing countries' agricultural production in the long run. These distortions have been the objective of considerable debate within the World Trade Organization (WTO) agreement on agriculture (AoA), where three "boxes" have been identified (amber, blue, green) to classify the degree of distortion of various domestic support policies, in the sense of their negative implications for trade of other countries. At the same time, developing countries are not affected uniformly by Organisation for Economic Co-operation and Development (OECD) policies owing to differentiated selective trade preferences between countries and heterogeneous trade positions at the country and household levels.

Moreover, the global environment under which the OECD support policies operate has changed over time, from endemic excess supply and falling real commodity prices, to rising prices from accelerating demand, driven in part by the rise of demand for biofuel feedstocks in light of the pressing need to face up to environmental impacts of climate change. While OECD support policies have created global distortions, developing countries are not affected uniformly by such policies owing to differentiated selective trade preferences between countries and heterogeneous trade positions at the country and household levels.

Nevertheless, several measures can be pursued by developing countries to mitigate the effects of distortionary farm support and stimulate agricultural production and development. Moreover, farm support in high income countries is not the only impediment to agricultural growth and poverty reduction in developing countries. Over the last three decades, public investments in agriculture in many least developed countries have declined in real terms. Since the onset of the structural adjustments in the 1980s, and the policy reforms that followed under the general push towards "liberalization", many developing countries experienced a disengagement from agricultural investments and spending not matched by the private sector and the results of these reforms have been at best mixed. Frustrated by lack of progress, many developing countries have grown wary of the so called "Washington consensus" whereby developing countries' governments were advised to get out of agriculture and be replaced by the private sector. The recent food price crisis (2006-2008) jolted many complacent governments in developing countries to reverse course and commit to new investments and support toward agriculture as the concern for food security took on a high priority status. The donors and developments agencies themselves have

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come around, accepting the critical importance of agriculture and there has been a noticeable shift in their programs, in the last two years with increased attention to agricultural development.

The paper provides a review of farm support in high income countries, and discusses options for support to achieve some of the same objectives in a less distorting fashion. It also addresses non-distorting responses that could be adopted in developing countries to support farmers, ensure a long term and sustained faster growth in agricultural sector, enhance food production and rural incomes, and lower poverty. The paper is divided into two parts. In part one, the paper focuses on the OECD farm support policies and their implications for market distortions in third countries; a particular focus will be given to decoupled support and the complementary policies needed to support developed countries farmers without resorting to distortionary support; other issues examined are risk mitigation and insurance related schemes, trade and market access reform under the Doha round, and biofuel policies.

The second part of the paper addresses the policy responses in developing countries that address both the challenge of policy-induced market distortions as well as seeking new impetus to revive production capacity to meet the growing demand for food. Among the issues addressed in the second part are the issues of investments, trade policy, effective input subsidies, insurance and risk management schemes, and carbon offsets under climate change. Our goal is to examine the issues analytically and arrive at recommendations as the types of policies that could be least distortive in achieving a given policy objective. We draw largely from the literature and key insights from two expert meeting consultations held at FAO Rome between December 2008 and May 2009 on this topic.

## 1. OECD FARM SUPPORT AND DISTORTIONARY EFFECTS

Current OECD agricultural support encourages production and discourages consumption of agricultural products within the OECD; this reduces the volume of global agricultural trade and tends to reduce commodity prices on the world market. It reduces returns to non-OECD agricultural producers and thus inhibits investment and agricultural development. Consequently, agricultural support in OECD countries is costly and distorts international commodity markets; it also disproportionately benefits wealthier households that own large amounts of agricultural land, it raises food costs, which disproportionately reduce the real incomes of lower income households (Skully, 2009). However, agricultural support is not uniformly distorting. Compared to producer price support, a tariff causes more trade distortion than an output-based payment because the latter increases both production and reduces domestic consumption, while producer price support only raises production. Thus the tariff causes a larger reduction in imports and a larger decline in the world price of the commodity.

The overall OECD support to farming has been remarkably stable over time, despite periodic reforms since the onset of the Uruguay Round. According to OECD, from 1986-87 until 2005-07, the value of OECD agricultural production increased by 53 percent, while total producer support increased by 10 percent. The ratio of producer support to the value of production declined from 40 to 29 percent. Market price support and payments based on output have decreased. Combined, support based on commodity output accounted for 82 percent of total support in 1986-88; in 2005-07 it accounted for 55 percent. Consequently, the aggregate trade-distortion coefficient for OECD agricultural support declined from 0.96 in 1986 to 0.74 in 2007. Also the estimated Producer Subsidy Equivalent (PSE) for all OECD agricultural support has declined from 39 percent of the total value of agricultural production in 1986 to 23 percent in 2007 (Skully, 2009).

These slow but declining levels of distortionary policies reflect a re-instrumentation of support policies in OECD countries. In the OECD countries, support based on commodity output is the primary means of producer support, while tariffs are the predominant form of border measure. Restrictions on market access (such as tariffs) by OECD countries account for almost all – over 90 percent – of these distortions. Market price support and payments based on output have decreased. Also, export subsidies and foreign surplus disposal, heavily used in OECD in 1980s, are now relatively minor.

OECD farm support policies are distinguished and categorized by the "transfer basis" of support (Skully, 2009). Transfer is made on the basis of output, input use, area planted, animal numbers, receipts, income and non-commodity criteria. Overall the distribution of support across different instruments has also changed significantly over this period. Market price support and payments based on output have decreased.

### 1.1 Decoupled support

Since the mid-1980s, when multilateral agricultural trade negotiations began under the Uruguay Round, many OECD countries enacted policy reforms which essentially re-instrumented the support instruments by introducing direct payments to producers; these tax-financed payments partially compensate for policy reforms such as reduced tariff protection and lesser reliance on product-specific support programs. One form of direct payment, decoupled support, has been introduced in the United States of America and the European Union. Decoupled direct payments are based on past, non-current, characteristics of the recipient's farm operation and are not contingent on producing agricultural output or employing factors in agricultural production, nor are they contingent on receipts, income, or current prices. The payments are financial transfers to individuals.

Direct payments distort output and trade, but to a lesser degree than tariff protection. Decoupled payments are introduced to replace pre-existing support policies: they represent an attempt to exit from agricultural support (Skully, 2009). They are a product of political and budgetary necessity. What recipients provide in return for decoupled support is refraining from opposing policy reform. Decoupled payments do not provide a direct incentive to produce a particular output or, indeed, any output; similarly there is no direct incentive to employ any productive factors. Decoupled payments do not yet account for a large share of OECD agricultural support but their share is increasing. From less than $2 billion in 1986-88 this form of producer support reached $48 billion in 2005-07 (Skully, 2009). Decoupled payments are now the second most important means of support to agricultural producers in OECD countries.

The distortionary effects of farm support are examined in the literature from the prism of their "degree" of coupling/decoupling from production and input use decisions. Payments based on area, historical entitlements, input constraints, and farm income are decoupled from current production decisions and hence have a lesser impact on production and trade. WTO defines decoupling only in the context of farm income support, but not in correcting for market failure or to provide for public goods. Decoupled payments can change with market prices, but they must be financed by taxpayers. Policies correcting for market failures or providing public goods normally affect production and need to be evaluated in terms of their being minimally trade distorting (Baffes and De Gorter, 2005)

Decoupled support has smaller production effects because these payments are fixed in value and not contingent on any current action by the recipient. However, while payments are not directly tied to level of output, payments themselves can influence future production decisions. This is because payments can reduce farmers' aversion to risk through the "wealth effect". Depending on how payments are disbursed, the variability of farm income can be reduced, hence reducing risks facing farmers, and lead to increased output. Also decoupled payments can affect farmers' investment and exit decisions by relaxing constraints facing them in capital and labour markets.

Using a household model framework, Skully (2009) examines how different types of households have different responses to decoupled payments and what characteristics must a decoupled policy have to ensure minimal production-distortion and trade-distortion effects. Decoupled payments may influence a recipient household's decisions through credit. The receipt of a decoupled income transfer by a net creditor household may simply be deposited into savings or invested in other financial assets; it increases household net worth but does not relax any binding financial constraint on the household. In contrast, a decoupled transfer to a credit-constrained household can relax the binding credit constraint and expand its feasible choice set. There are at least two ways decoupled payments can relax the household's financial constraint. The direct effect is that the payment increases current cash flow. The indirect effect may arise because the entitlement to a stream of decoupled payments may improve the recipient's credit rating.

Skully (2009) argues that decoupled support is redundant since most recipients do not need government support. Existing decoupled support is based on agricultural land ownership or use in a specific base period. Much of the value of coupled agricultural support is capitalized into the value of farmland; reducing coupled support will reduce farmland values. Linking decoupled support to land partially compensates or mitigates this decline in asset values. Consequently, the value of decoupled support is correlated with land ownership and large landowners receive most of the payments. Thus most decoupled support goes to wealthy recipients and the additional income has little impact on their decisions. There are low-income recipients but they receive a very small share of payments and they account for a very small share of agricultural output. The small production impact we observe from decoupled payments in large part comes from recipients that have low incomes or that can not obtain credit: additional income can influence output in such cases, but the quantity increase is low. The bulk of agricultural output in the OECD is produced by households that are wealthier than the average household. With relatively complete markets and higher farm household incomes the scope for production effects under decoupled support is lower.

Besides reducing the level of distortions, OECD decoupled support policies could also strengthen the capacity to maintain an agricultural production "reserve". Such policies, which could include support for land set asides, support for technology and farm human capital skills, incentives to maintain set-aside land in production ready and environmentally sustainable condition, and other similar policies, could be a powerful alternative to physical and very expensive "commodity reserves" which are not only hard to organize, but also very questionable in their effectiveness. On the other hand set-aside productive land can be brought into physical production in high income countries within six to ten months (the recent supply response is evidence to that), providing a powerful reserve to any future food shortages, while at the same time not distorting current global markets with overproduction.

### 1.2 Market access restrictions to trade

It is commonly acknowledged by economists that market access restrictions imposed by OECD countries on third countries products have greater impact on agricultural trade than domestic support. According to the Global Trade Analysis Project (GTAP) database estimates of support to global agriculture and processed food in 2001, import tariff barriers represented 81.4 percent of total support to agriculture in all countries (tariffs accounted for $691 billion, direct domestic subsidies accounted $97 billion, and export subsidies only $61 billion) (Anderson, Martin and Valenzuela, 2006).

Market access restrictions come in the form of tariff barriers and a wide range of non-tariff measures (standards, seasonal restrictions, tariff-rate-quotas, etc.). The relatively higher prominent role of market access versus domestic support can be explained by different factors. First, from the economic theory of protectionism, tariffs represent a double distortion acting as both a consumption tax and production subsidy (Corden, 1977), whereas domestic support is mostly a production subsidy. Second, tariffs are widely adopted in agriculture and all countries use them, developed and developing ones, even in cases where no domestic support is present; moreover tariff dispersion is high not only in terms of products but also in terms of partners (because of regional agreements, preferential schemes and tariff rate quotas).

Market access to agricultural trade is still restrictive for developing countries. The 70 countries most penalized by agricultural protectionism are developing countries (Bouet and Laborde, 2009). However, market access restrictions are not uniform across products, countries, and groups of countries, depending not only on developing countries' income and development levels but also on whether countries are subject to MFN or preferential tariffs, on countries' product specialization, and on their net trade position. Exports from developing countries still face high import barriers, except for countries that benefit from preferential tariff access such as under the Generalized System of Preferences (GSP), the African Growth and Opportunity Act (AGOA), the Everything But Arms (EBA) initiative, etc.

Tariff liberalization studies converge in concluding that tariff liberalization accounts for the lion share for potential increases in trade and global welfare (much more than domestic support). Not only tariffs hinder trade directly (being equivalent to a consumption tax plus a production subsidy) but they are also the most widely used instrument of trade protection. Import barriers account for over 80 percent of total support to agriculture in all countries (Anderson et al., 2006). Trade liberalization studies concur that tariffs are by far the main source of distortions, and account for more than 90 percent of expected benefits and that developing countries, as a group, could be large beneficiaries of these reforms.

However, developing countries are a very heterogeneous group, some net exporters other net food importers and so the impact of protectionist policies in OECD can be quite different from one country to another. Also trade policy and impacts of liberalization affect LDCs (least developed countries) differently from MIC (middle income countries). A recent assessment by Bouet et al. (2008) of the Doha Round latest proposal as of 2008 shows that some of the LDCs will lose out from the reform, if they rely on few commodities for exports and export high shares to markets that offer preferential treatments; LDCs from Africa that export more to EU are in vulnerable position.

Market access restrictions are not limited to import tariffs. Non tariff barriers can often impede trade, and in the case of agriculture, severely in many cases. Disdier, Fontagné and Mimouni (2008) show that Sanitary and Phyto-Sanitary (SPS) and Technical Barriers to Trade (TBT) measures are highly prevalent in OECD agriculture and that they influence negatively OECD imports. These authors' estimations also suggest that SPS and TBT reduce significantly Developing Countries and LDCs exports to OECD countries while having no significant impact on trade between OECD members. Clearly, a new Doha round agreement must place a significant ceiling on commodity-based distortionary farm support and must include significant reductions in market access restrictions

One way to remedy the perceived inequity of seeing OECD governments spending large amounts of resources to support their agricultural production is to propose a counter-measure as compensation for developing countries agriculture, especially for those countries badly in need for assistance to prop up their production capacity, particularly among the resource-poor countries. The basic idea is for OECD countries to offer compensatory financing for developing country producers as a way to achieve fairer trade. One option is to agree that a certain percentage of farm subsidies in OECD countries be put into a global development fund to be distributed to eligible developing country (especially LDC) farmers along established criteria for eligibility, such as the estimated distorting effect on them from developed country policies. The funds could be used for projects to raise production, ensure sustainability of productive resources, agricultural research, and improvement of local human capital that is tied to agriculture.

### 1.3 Risk Management and Policies in OECD

As OECD farm support shifts from commodity based to decoupled measures, farm incomes have become more variable, and safety nets in the form of risk mitigation measures, such as revenue or weather insurance are been increasingly relied upon to provide protection from unpredictable swings in farm incomes. Several agricultural policies have been justified, through time, with the attempt to reduce farmer's risks and stabilize agricultural income. For instance, support policies adopted by OECD countries until the late 1980s were directly aimed at reducing price and income variability, while at the same time pursuing a wider reliance on domestic production. It is known, however, that rather than reducing variability, price support coupled with the necessary market protection has resulted mostly in a transfer of instability from some markets to other markets; and specifically from OECD markets to the rest of the world. The need to bring agricultural tariffs and agricultural policies in the GATT -- and later in the WTO -- resulted, *inter alia*, from the increased trade integration and the related improved awareness of the instability that was being transferred from some markets to others.

Considering the major recent agricultural policy developments in the OECD – particularly the 2008 US Farm Bill, Canada's Growing Forwards Framework, Mexico's increasing support to price hedging, the Australian on-going revision of drought policies and EU Health Check of the Common Agricultural Policy - there seem to be an increasing attention to risk and the risk-related effects of agricultural policies (OECD, 2009).

One popular idea in OECD countries has been that insurances can substitute for market intervention as a tool to shield farmers from income and production risks. Insurances, *per se*, are market-based products, which can be sold at a market price; and such price reflects the degree of risk attached to risky event, as computed by the insurance company. The decision of a farmer to purchase insurance should, therefore, depend on her/his own risk consideration, and should not require public intervention. The only public good that the State may supply into this market is information, which may not be universally and/or symmetrically available: hence validating, certifying and diffusing the data required to assess probability distributions of risky events is virtually the only role that public policies should logically play in the insurance market.

Yet agricultural insurances have been widely subsidized in OECD countries; they are classified as "green box" or "minimally distorting" policies in the WTO negotiation. In the US, for instance, farm insurance and payments under crop and weather insurance are projected to reach 22 billion USD in the 2008-2012 period; this represents a substantial share of total farm support. The EU has also started re-examining its current agricultural insurance schemes, based on the observation that existing ones tend to be inefficient, expensive, and distortionary, as they entail high transaction costs and tend to increase the expected returns of covered products.

Sources of risk in agriculture are numerous, diverse, and often interrelated (OECD, 2009). They include prices, as well as a diversity of weather, pests and diseases hazards, or personal circumstances. Unexpected changes may occur in access to services such as credit, finance, or in the legal framework. Managing risk is an important part of farming, and improving risk management is a concern for several Governments in the OECD. Risks that are frequent but do not imply large losses are typically managed on the farm. Risks that are infrequent but generate a large amount of damage to farm income are likely to fall under the catastrophic risk layer, for which market failure is more likely. In between these two layers there are intermediate risks for which some insurance or market solutions can be developed. It is important to allow solutions to each type of layer to develop, so that a variety of instruments is available to farmers.

Given the prevalent government support to agriculture in OECD countries, it is difficult to disentangle risk management from these policies. All agricultural policy measures have an impact on risk. Some of them, however, are specifically designed to reduce price, yield or income variability, or to smooth consumption, and thus help farmers in managing risk, either because they prevent or reduce the occurrence of risk (risk reduction), or because they limit the effect of risk on income (risk mitigation) or consumption (risk coping) (OECD, 2009). An example of risk reduction measure is vaccination for animal disease control. Market price support (MPS) measures, which stabilise domestic prices, also reduce price risk. Risk mitigation and coping can operate through established (*ex ante*) mechanisms, such as countercyclical payments with variable rate, subsidies to insurances, futures, options, income tax smoothing, diversification, or income stabilisation programmes. *Ex post* interventions, such as disaster payments include mainly *ad hoc* assistance to compensate income losses in the aftermath of a catastrophic event. In the U.S. subsidized insurance, which was started since 1980, seems not to have replaced the need for disaster assistance (Glauber, 2004). On the other hand, evidence from the EU shows that countries where insurances are less common spend more in *ex post* disaster payments (Garrido and Bielza, 2008). OECD (2009) report that risk-related policies account for a significant share of the Producer Support Estimate in OECD countries, about 51 percent in the European Union and 63 percent in the US in for 2002-07 average period.

The existence of support policies that reduce risks may reduce the willingness of farmers to engage in on-farm mitigation strategies, or to purchase insurances. However, policies may tackle risks which are not insurable by the private sector, and are complementary to insurable risks, and reduce information gaps and asymmetries, hence leading to an increase in the demand and supply of market based risk management tools. Evidence for the OECD indicates that the cost of yield insurance in excess of a "fair" premium increases with diversification, and that the proportion of planted area insured decreases with the size of the Single Farm Payment for major crops in the EU (OECD, 2009). Evidence also indicates that market-based risk management tools are better suited for reducing risks; but other support measures, such as area payments, are found to be more transfer efficient in terms of profits or income, and less efficient in reducing risk (OECD, 2005).

Another policy dilemma arises between the objective of reducing risk and that of minimising the distortionary impact of policy measures on production and trade. In fact, all programmes which affect variables in the current period, such as prices or revenues, do affect production and trade in a number of ways. Particularly, dynamic effects on production may materialize through an increased ability to invest ("insurance effects"), or through a reduced risk of bankruptcy (Vercammen, 2000; 2003). Evidence indicates that measures with larger impact in terms of risk reduction, such as crop insurance and price hedging, also have relatively larger impacts on production (OECD, 2005), as they can modify substantially market incentives.

### 1.4 Biofuel Policies

A growing area of complication in agricultural policies is the role of biofuels and the increasing linkage between agriculture, energy, and climate change mitigation policies in general. Since a major driver for biofuel push in OECD countries is due to production subsidies, tariffs and mandates, these support policies are becoming more in-meshed with traditional agricultural support policies adding a new dimension to the distortionary effects on agricultural production and trade. Proponents of biofuel subsidies argue that these subsidies may lessen the use of farm subsidy programs, as biofuels offer a new domestic market for agricultural products that could stimulate demand and push up prices, thus ultimately reducing the level of farm-subsidy payments. Moreover, biofuel growth tend to raise world prices thus masking the price depressing effects of traditional farm policies, making it more difficult to sort out the distortionary effects of each.

Biofuel policies are not agricultural policies but influence agricultural output and trade. Biofuel policies have the opposite effect of traditional market-price-based agricultural support: they effectively subsidize the consumption of biofuel feedstocks – maize for ethanol and oilseeds for biodiesel – and this increases commodity prices and reduces net commodity exports. Thus current biofuel policies tend to benefit net exporters of cereals and oilseeds and to reduce the real incomes of net importers. Feedstock use is expanding rapidly and has raised concerns about global food security. In the short-run grain and oilseed prices are likely to be higher and more variable than in the absence of biofuel programs. It appears likely, however, that alternative feedstocks will become economically viable, replacing maize and oilseeds and reducing the growing diversion of farmland to energy use.

*In summary, this review of OECD farm policies and their distortionary effects, shows that overall, OECD farm support have been stable over many decades with increasing protectionism up to mid-1980's when it began slightly declining; this coincided with the onset of the Uruguay Round which succeeded in bringing agriculture under the WTO disciplines. Since the mid-1980's, OCED farm support policies followed a more or less steady pattern of policy re-instrumentation characterized largely with a shift away from commodity-based (and highly distortive) support to more or less decoupled support that less distortionary effects on production and trade. From the perspective of aiming to expand non-distortionary policy support, further decoupling in OECD support policies should be encouraged and expanded to more OECD countries and for all agricultural commodities. Also with increased decoupling there is greater interest in OECD toward policies that directly reduce price and income risks in other means (such as subsidizing insurance). However, to avoid creating new sources of distortions, it is important that agricultural insurance support policies in OECD deal mostly with extreme and unpredictable agricultural risks that cause market failures, and be more market-based so as to provide non-distortive safety nets to farmers.*

*From trade perspective, this review showed that the distortionary effects of border policies that restrict market access are larger than those of domestic support. As a consequence, much more emphasis on slashing market access provisions in the Doha agenda should be the main aim of the Doha negotiations.*

## 2. DEVELOPING COUNTRIES FARM POLICIES

Pubic support to agriculture in developing countries is essential for raising productive capacity, stimulating growth, improving income and reducing overall poverty. Legitimate public investments in agriculture in developing countries can be justified to correct for many market failures and to achieve higher productive capacity, reduce income and price risks and uncertainty, or preserve natural resources and the environment. Examples of the types of non-distorting policy support for developing countries are summarized in Table 1.

**Table 1. Types of non-distorting farm support for developing countries' agriculture**

| Policy Goals | Types of Government (public) interventions |
|---|---|
| **Maintain or improve productive capacity** | • Research and development (new varieties)<br>• Better management techniques<br>• Efficient use of inputs (water, fertilizer, pesticides)<br>• Develop input market systems<br>• Improved storage, processing, product quality<br>• "hard" infrastructure (irrigation, land restoration)<br>• "soft" infrastructure (information systems, lowering transaction costs, extension of best practices) |
| **Correct market failures** | • Facilitate exchange between producers/buyers<br>• Provision of credit (subsidized)<br>• Technology dissemination/farmers training<br>• Support producers organizations/inter-professions<br>• Promote value chain development |
| **Reduce income and price risks/uncertainty** | • Support information for insurance markets<br>• Market information systems for exchange<br>• Investments in post-harvest storage<br>• Veterinary services to livestock<br>• Insurance/safety nets against crop failures, droughts..etc |
| **Better food security and lower hunger** | • Foster rural employment<br>• Targeted input subsidies (fertilizer, seeds)<br>• Storage/safe processing for staple foods<br>• Subside credit to farm and off-farm activities<br>• Staple food/cash crops promotion/demand creation<br>• More R&D in staple food varieties, improved techniques<br>• Investments/subsidies in post-harvest storage<br>• Quality control for stored grain<br>• Improve processing for perishable staples |
| **Preserve natural resources and environment** | • Soil fertility management<br>• More efficient use of water (proper pricing)<br>• R&D in varieties adapted to climate change<br>• Best practices for less pesticides |

Source: Compiled by authors

### 2.1 Agricultural Investments

In developing countries the question is how to ensure farm support in order to increase food production and ensure food security and other growth related goals, without generating large distortions or impeding progress toward an open international trading system. In the last 20 years, many developing countries have steady reduced spending and investments in agriculture and the latter has received a disproportionately small allocation of public resources (Bezemer and Headey, 2006). Likewise, foreign aid to agriculture has also contracted during this period. DFID (2005) shows that absolute global assistance to agriculture decreased from $US 6.2 billion to $2.3 billion between 1980 and 2002 (expressed in 2002 prices). Thus, agricultural aid per rural inhabitant sharply declined in the past 20 years.

This marked de-emphasis of agriculture in developing countries over the past two decades is partly blamed on the so-called "Washington Consensus" in which donor/development agencies led by the World Bank and IMF pushed developing countries to scale back public role in agriculture and promoted privatisation and market forces to steer growth. Bezemer and Headey (2006) show that market-oriented reforms ("liberalization") in LDCs, while contributing to reducing the anti-agriculture biases, nevertheless, coincided with reductions in agricultural expenditure. These reforms had profound effects on the agriculture sector, since privatisation didn't quite take off for lack of prerequisite conditions and resulted in a net disinvestment or simply elimination of the many public policies and institutions (e.g. marketing boards). In some cases, the dismantled public agencies were viewed as constraining private sector development; while in other cases the motivation was to remove inefficiency or drains on public resources and their adverse effects on macro stability. Consequently, public spending on agriculture declined at the same time as the lowering of net taxation of agriculture. The effects of these dual-policy reversals within agriculture has been mixed (Bezemer and Headey, 2006).

The real challenge today is to reverse this trend and augment investments in agriculture and stimulate growth, while learning from recent experiences and failures. Recent developments point that such reversal is possible. The global food crisis (2006-2008) jolted many governments in the developing world to begin paying attention to agriculture after a long period of neglect, most notably in Africa where calls for sharp increases in agricultural expenditures are heard in many capitals. Even the development aid/donor community have loosened their resistance to direct public intervention and have begun reallocating more resources to agricultural development. However, the challenge is to avoid measures that would introduce large and detrimental distortions, impede the move toward a more open trading system and avoid focusing on short public expenditures that can neither be sustained nor truly contribute to long term rise in agricultural productivity and sustainably improved farm incomes. Learning from the recent experiences, both the successes and the failures would help. And the focus should be not so much on just spending money at programs and initiatives, but rather tackling institutional, bureaucratic as well as human capital deficit challenges. The latter point is particularly critical for Africa, where it has been shown that government spending in human capital is strongly linked to economic growth (Yu, Fan and Saurkar, 2009)

### 2.2 Policy-induced distortions, trade policies, and Doha Round

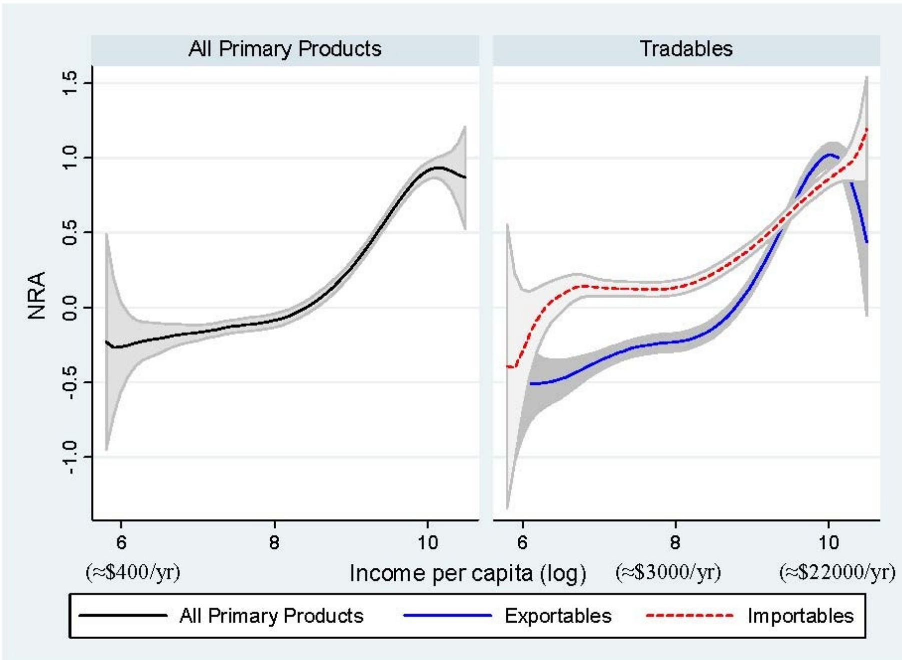
#### *A. Agricultural Distortions*

An important element in promoting agricultural growth is trade and policy-induced distortions that limit its potential. A recent World Bank study estimated agricultural distortions for 75 countries from the period of 1955 to 2007 (Anderson, 2009). In this study, agricultural distortions were proxied by the Nominal Rate of Assistance (NRA), defined as the percentage by which government policies have raised gross returns to farmers above what they would be without the government's intervention. For each country, agricultural and non-food products were separated between importables, exportables and non-tradables and an NRA coefficient was estimated for each.

In developing countries farm policies have been driven largely by the need to accelerate a transition from low income agrarian structures to more developed industrialized and service oriented economies. The overall effect of such policies, as measured by NRA, has been largely to tax producers (namely negative NRAs). In the process, the agricultural sectors in many countries have faced negative policy biases and low growth, while inducing increasing import dependence. However, when average incomes grow (typically at a per capita income level of USD 8000 or more), the type of farmer support in developing countries seems to turn positive and seems to follow a pattern similar to that of now developed countries, namely NRAs increase as the share of agriculture in the economy declines and average agricultural and total incomes increase. The results from the World Bank study bore this out by showing that broadly developing countries taxed agriculture via price and trade policies from the early 1960s to the late 1970s/early 1980s before gradually reducing the taxation and, by the mid-1990s, switching to slightly positive assistance to them in aggregate (Figure 1).

By contrast, high income countries supported agriculture and that support rose steadily from the 1950s to the late 1980s before declining slightly over the 15 years to 2004. Within countries, farm support and resulting distortions were more pronounced for importables than for exportables or non-tradables. Commodities that received the highest form of support included rice, sugar, dairy, beef, poultry and cotton. Trade measures at the border (export and import taxes or subsidies and their equivalent from quantitative trade restrictions and multiple exchange rates) accounted for 75 percent of the total NRA for developing countries and over 90 percent for high-income countries.

**Figure 1: Average Nominal Rate of Assistance (NRA) to agricultural producers as a function of country per capita income**




Source: Masters (2009)

When expressed on per farmer basis, the gross subsidy equivalent (GSE) of these distortions varies greatly between high-income and developing countries. In 1980-84 the GSE in high-income countries was already around $8,000 and by 2000-04 it had risen to $10,000 on average or $13,500 when 'decoupled' payments are included. By contrast, the GSE in developing economies was -$140 per farmer in the first half of the 1980s and rose to around $50 per farmer by 2000-04 or about less than one percent of the support received by the average farmer in high-income countries. Clearly, developing countries as a whole managed to reduce or even reverse the long-standing anti-agriculture bias via changes to prices and trade policies; unfortunately, the other side of the coin was a steady decline in investments and public expenditures on agriculture since the 1980's, a dual policy path that, for too many developing countries, had only mitigated results (if not outright negative in some cases) in terms of agricultural growth.

*B. Trade policy and Doha Development Round*

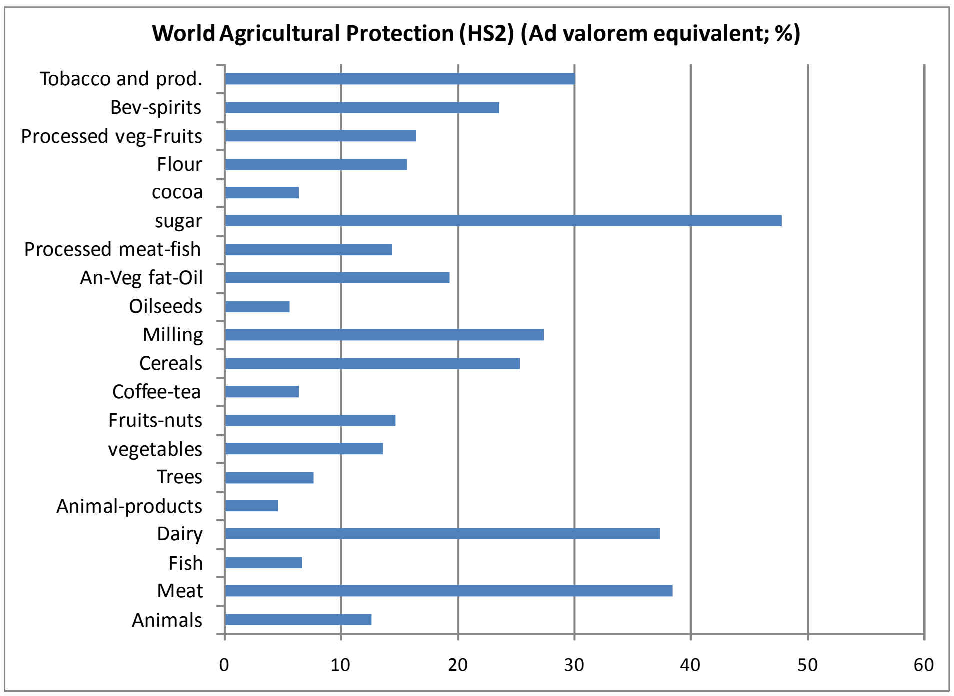
While slashing market access restrictions from high income countries would provide a significant boost to agricultural trade and hence production and growth in developing countries, the latter also need to lower their own often high border protections on their imports to fully benefit from a more open trading system; this is particularly important in light of enormously underexploited exchange opportunities in regional and south-south trade.

Tariff levels remain high but vary widely by region and countries and there is great deal of tariff dispersion between countries. Dispersion of agricultural protection between countries is high in Africa, Asia, and low in South America. In Africa, agricultural protection is relatively low in Western sub-Saharan Africa, higher in the

South African region, and even higher in the Central African and North African regions. Tariff dispersion is particularly high for Middle Income Countries like Egypt (41.5 percent), India (58.4 percent), Morocco (40.8 percent), Nigeria (42.6 percent), Thailand (38.8 percent), Tunisia (46.3 percent) and Turkey (35.3 percent) (Bouet and Laborde, 2009). The agricultural exports of 108 countries out of 183 are restricted by average taxes amounting to more than 15 percent, 29 countries by average taxes amounting to more than 30 percent and five by more than 50 percent. In terms of agricultural trade diversification, least developed countries (LDCs) rely precariously on a very small set of traded products for their trade; by comparison HICs and MICs tradable product mix is more diversified.

On a product basis, agricultural protection is particularly high for a small number of commodities such as sugar, meat products, dairy, and tobacco and beverages (see Figure 2). Tariff escalation is still sizeable and the coexistence of ad-valorem with specific tariffs makes protectionism volatile. For example border tariffs are higher on average for meat products than livestock, milled products than cereals, and processed food than raw commodities.

## Figure 2: World agricultural protection at the HS 2 level




Source: Bouet and Laborde, 2009

Another factor that needs revisiting in light of its impact on developing agriculture is food aid. The issue has become increasingly contentious. It is also one of a handful of significant points of disagreement in current agricultural trade negotiations under the WTO's Doha Round, as the United States of America and the European Union wrangle over the possible trade displacement and developmental effects of food aid. Food aid is often blamed for creating disincentives for small farmers in recipient countries by depressing food prices, distorting markets, discouraging overdue policy reforms and fostering dependency.

During last year's global food shock, many low income food deficit countries (LIFDCs) were unable to import enough food to maintain domestic consumption levels because of trade finance restrictions imposed by export financing institutions in developed countries. This problem is a recurring one and was supposed to be dealt with under the Marrakesh Decision of the Uruguay Round but was never tackled. A way to deal with it would be to promote the creation of a Food Import Financing Facility (FIFF). The purpose of such a FIFF would be to provide additional trade financing to the agents of LIFDCs for the cost of excess food import bills, so as to maintain normal levels of quantities of imports in the face of price shocks, or to make it possible to import extra quantities in excess of normal commercial import requirements. FAO has worked out the modalities of such an international scheme, the idea of which is supported by export financing banks.

Commodity export earnings instability has been a long standing problem for low income commodity dependent economies. Existing or past international instruments are being debated a new. Examples include the EU's STABEX system (devised for ACP countries), SYSMIN (for mineral sector) and the IMF's Compensatory Financing Facility. The STABEX was devised for the benefit of ACP countries that are party to the Lome Convention with the European Union. Through this policy, the EU attempted to stabilize the export earnings of the ACP Countries. The STABEX objective was to reduce the instability of the agricultural export earnings of the developing countries which signed the Lome agreement. A commodity-by-commodity analysis by Aiello provided an empirical evaluation of the effects of the financial transfers disbursed by the EU. The results showed that STABEX had a positive impact on the sectors in which the drop of export earnings occurred (Aiello, 1999).

However, both the STABEX and SYSMIN (minerals) subsidy systems have been criticized for being procyclical rather than compensatory, and also contributing to the reinforcement of lop-sided production structures and not to the diversification of production. As a result, the EU has reduced reliance on these subsidy schemes. Agricultural growth in Africa can only proceed through development of a diversification and value addition strategy, and not reliance on exports of raw materials alone. Nevertheless, a new type of policy to manage export earnings risks would be to link commodity related compensatory payments to index based financial products, so that compensation can be made automatically and objectively.

### 2.3 Input subsidies and enhancing production capacity

Input use (especially seeds and fertilizers) is obviously an important factor to improving agricultural production, productivity and farm income. Use of improved (selected) seed varieties is often associated with markedly higher yields. Likewise, lack of access to fertilizer is commonly cited by farmers as a major constraint on yields and production. Obviously, when such necessary inputs are underutilized, this inevitably points to one or different types of market failures. And input subsidies have often been used as a mechanism to stimulate agricultural production and induce agricultural growth and rural development.

In Africa, there has been a renewed interest in input subsidies to stimulate domestic production for enhanced food security, especially after the aftermath of the recent food price crisis (2006-2008). Such pressing demands are coming not only from the African governments, but also NGOs and supported by the international donor and development aid institutions, who have been chastened in the past by the failures of liberalized policies in supporting broad based agricultural development, particularly sustainable intensification of staple food crop production.

The question is whether input subsidies are a wise approach to spend public resources; and if so what conditions are required for successfully meeting their intended goals. Equally important are the lessons from past input subsidy experiences can we draw for designing better programs in the future.

The key criteria for input subsidy success is to entice farmers who currently do not use fertilizer to do so; this means an input subsidy program would ideally avoid a situation where input subsidies are transferred to farmers who already use fertilizer without the subsidy; target products with high supply response potential and with inelastic demand and supply among poor producers and consumers (e.g., staple grains). Input subsidies should also strive to avoid rent seeking from straight transfers resulting in economic (deadweight) losses (Dorward, 2009).

Effective input subsidies are best applied to overcome market failures constraining their use, especially in the production of staple crops (grains and tubers) when input use is sub-optimal. To be effective, input subsidies must also be targeted and rationed to limit costs. This is because a general input subsidy is difficult to channel to smallholders unless there is a limited number of tightly controlled supply chains, clear ways of identifying intended beneficiaries, and a high degree of discipline and control of private fertilizer transactions (Dorward, 2009). Consequently, effective subsidies need not be large scale and across the board subsidies, for that would make them extremely costly with large transfers to recipients, not all of whom are in need of such outlays, and rent seeking behaviour from various stakeholders (especially the non-poor).

Often input subsidies are not enough by themselves. To be effective, they require large investments in complementary investments, output market development policies and institutional support. If successful, input subsidies could help develop a functioning input market and improved supply systems, build farmers know-how, and induce dynamic and spill over effects on rural economies and other agricultural activities beside the targeted commodities.

Yet, input subsidies have often run into ineffective or inefficient implementation entailing substantial risks in terms of costs; lack of exit strategy; practical difficulty of targeting the input subsidies to particular farm types; and inciting over use of inputs and adoption of input-intensive rather than labour-intensive management practices. There is also the problem of resource (mis)allocation between subsidising inputs and other priorities (e.g. research, investment in infrastructure) and on the targeted beneficiaries of the subsidies (consumers, producers, taxpayers). Moreover, input subsidies are always subject to the type of political economy considerations that have derailed past programmes in the past, especially for rationed input subsidies which create opportunities for those controlling the subsidies to divert them from their intended beneficiaries, be it users (subsidies not going to those targeted producers) and/or products (subsidies not going to those low productivity crops most in need of raising input use for greater productivity).

There are few cases of success stories relating effective use of input subsidies in developing countries. In many cases, such programs have been plagued by weaknesses of design and implementation (Dorward, 2009). Such weaknesses are often linked to the failure to develop an effective input supply and delivery system to the farmers, hence limiting any success from the intended program. The failure of past input subsidies also stems mainly from the lack of careful targeting and the absence of monitoring and evaluation of how these programs worked.

A review of several fertilizer subsidy programmes in Africa by Dorward (2009) shows that often these input subsidy programs tend to over emphasise setting specific production targets without due consideration to consumer interests or to wider pro-poor economic growth. As a result, input subsidies programs as currently implemented in many African countries are rarely implemented with necessary complementary investments in input market infrastructures and other market instruments (such as institutional support to farmers organizations) needed to ensure effective implementation of such programmes in the long run.

In face of these institutional and endemic implementation difficulties in developing countries, the question is whether input subsidy is the best way to encourage higher input use when desired. Are there alternatives to input subsidies or if justified, how can input subsidies be made part of broader strategies encompassing other critical market failure remedies that can also result in more optimal use of inputs in agricultural production.

One alternative to direct input subsidies is to devote the limited public resources to the development of effective input delivery system that can ensure greater input accessibility and affordability. Examples of intervention under this form of support include funding seed multiplication farms, support local production/processing of fertilizer, developing facilities to process imported input formulas, support to agronomic research focusing on developing adapted fertilizer formulas for specific crops and promote extension demonstration for best practices in input use, subsidizing infrastructure and transport of inputs from factory to local points of sales, etc The advantages of investing in input delivery and marketing systems are the potential widespread benefits to a large number of producers across a number of crops, allowing farmers to make optimal decisions on how much input to use and for which crops. Besides the clearly public-good dimension of such support, it also avoids the pitfall of inducing input over use, and allow for fewer opportunities for leakages and wasteful rent seeking behaviour. Still the actions may not be enough to correct for too high price of inputs (fertilizer) relative to produce prices. In such case, small scale farmers may still be discouraged from input use from high costs.

Another channel to enhanced input use is better access to credit. Credit access is considered a prerequisite to input use in most farming situations. One alternative to direct input subsidy is to provide subsidized credit to farmers to finance input purchases. This form of support would overcome one of the most endemic causes of underutilization of inputs among small farmers. In fact, in many cases past state interventions on stimulating input use involved subsidized credit. Such approach has the advantages of avoiding the input-overuse possibility from subsidy and would also allow optimal decisions by farmers in deciding on the mix of input to use. However, this approach too has limitations. Even with subsidized and accessible credit, the price of unsubsidised inputs may still too high relative to product prices, and hence remain out of reach for small farmers who would need it the most. Also, misuse of agricultural credit programs in the past led to financial losses, and credits were often applied regressively (loans to well-connected and wealthy borrowers). In fact the demise of the farm credit programs in many developing countries allowing farmers to purchase inputs, is one of the justification for opting for significant subsidies to inputs as the only option that will significantly incite small poor farmers to access and use inputs such as fertilizer.

### 2.4 Agricultural risk, insurance markets and government role

The role of the public sector in reducing agricultural risk could take many forms including supporting market-based insurance schemes. For insurance, the Government role can range from simply providing the underlying regulatory framework for private insurance to subsidizing premiums or co-insurance to private schemes in cases of catastrophic losses.

The type of government role and its scope is determined by the type of risk, it frequency, and the scope of resulting losses. The World Bank (2005) offers a useful framework, termed risk layering, to categorize risks in terms of their insurability. Three layers are distinguished: (i) retention layer, (ii) insurance market layer, and (iii) tail risks layer. Layers are determined by the specific risks of each environment; but their size also depends upon the market for agricultural services, and government's policies which affect decision making (Conforti, 2009).

The first layer (retention layer) implies expected types of risks that are frequent and losses are small or manageable and are born by producers or operators. Here additional insurance normally is not required. The ability of farmers to retain small and frequent losses - that is, the size of the retention layer - depends upon access to agricultural services, and the functioning of the relative markets, such as those for credit, finance, transport, storage, or extension. Where such markets are incomplete or uncompetitive, farmer's ability to retain risks is hindered. In these cases, small scale farmers are forced to rely on other mitigation or informal ways to smooth consumption, which may perpetuate subsistence, hinder farm capital formation, and limit agricultural productivity growth (Carter, 2008). Farm support policies, such as those listed in Table 1 can play a role in alleviating these constraints.

There are other types of unexpected events that cause larger farm losses, but which can be mitigated by risk pooling via insurances. However, the agricultural insurance market remains largely underdeveloped in most developing countries, and for multiple reasons. In most cases, farmers are simply not aware of insurance programs or cannot properly understand how their work. Premiums may be out of reach for poor farmers and high transaction and delivery costs in remote rural areas may undermine incentives for insurance companies to operate. Lack of information (on risk exposure) and high transactions costs are main causes behind market failures in insurance. In those small cases where agricultural insurance do exist, the record has been mixed, and their sustainability outside government support is often questioned (Conforti, 2009).

One approach to insurance termed index-based insurance has been promoted as a solution to the problems facing conventional insurance programs in developing countries context (World Bank, 2005). The index-based (or parametric) insurance rely on using pre-determined indemnities that can be triggered by changes in an index whose values are expected to affect individual subscribers to a pre-determined extent. Indexes replace costly *ex-post* damage assessments by insurers, and help reduce information asymmetries (required to calculate risk exposure). However, the approach implies that the subscriber assumes the so called basis risk, that is no compensation is paid for damages which exceed – or are short of - what is predicted by the correlation between the occurrence of an event (such as annual rainfall below a given amount) with the expected damage (Berg and

Schmitz, 2006). Parametric insurances have been developed mainly on weather parameters, based on the notion that climatic variability is the first most important reason for vulnerability (OECD, 2008). But there may be other index types to use such as area-based yield insurances.

We have seen that governments can play a variety of roles in correcting for market failures blocking the development of insurance markets and/or help farmers better cope with non-insurable risks via strengthening basic agricultural service markets (credit, extension, storage, market information and price policies). To overcome the market failures (lack of or asymmetric information resulting in high start up and transaction costs) that prevent the growth of private insurance markets (including index-based programs), government can provide support through a variety of channels including investments in market information systems and related infrastructure required for proper functioning of private or market based insurances. For those infrequent but high (catastrophic) loss events (tail risks layer), governments can also help with co-insurance since these types of risks cannot normally be handled by private insurance without running insurance firms out of business.

However the record of government interventions in formal insurances schemes has not been very successful. Conforti (2009) surveyed several developing country experiences with agricultural insurance schemes and found that there are cases where informal mechanisms as well as micro-insurances have been crowded out by public intervention. Conforti divided country cases studies into three categories, those cases where government assume minimum role providing no more than contract regulation and information disclosure; those cases involving government contribution to re-insure against covariate risks and extreme events; and those cases where government directly contribute to premium subsidization. In country cases where farm insurance is privately supplied as in Argentina, Ukraine and India, their coverage has been extremely small (no more than one percent of all farms) and typically covering larger farms and high value products only. Examples of government premium subsidization from Mauritius, India, Morocco and the Philippines, were found to be plagued with inefficiency and misuse. Even in schemes using index-based insurances, only few successes could be found, as in the case of Mongolia's livestock index based insurance where government cover extreme events with assistance from World Bank loans. For other cases of government support to index-based insurance schemes such as in India (through microfinance) or in Malawi (through farmers organizations), the verdict is rather negative on their performance.

Experiences learned from the above case studies indicate that governments tend to intervene mostly via premium subsidization and that these experiences have shown more failures than successes, due to widespread inefficiencies and sometimes misuse. Clearly, new and innovative approaches are needed. It is not enough to say we need to promote market-based insurance and other risk mitigation schemes. What is needed is to remove or correct for the underlying market failures preventing risk management solutions from becoming a normal component of farmers choice (and decision making) set. This begins with improving the critical agricultural service markets (credit, information, and other production and marketing smoothing options). Next, encouraging the emergence of fully private insurance system in poor rural areas, by involving pre-existing organizations (such as farm organizations, micro-finance institutions) and Government, donor or NGO temporary support with "start-up" costs and help them develop building trust and consolidate relations. Where subsidized premiums to private insurance can be justified, this must clearly be carried out in a context of a clear exit strategy when benchmarks for transaction costs, market thickening, and coverage for small holders and producers of staple crops (not just high value crops) are attained.

### 2.5 Climate change, carbon offsets and developing country agriculture

Another emerging area, with potential implication for agricultural growth and development in developing countries is the possibility of the use of carbon offsets in developed countries to promote carbon reducing but at the same time productivity enhancing agricultural technologies and investments in developing countries. Currently many developing countries governments are not willing to tackle agriculture–climate change linkage for fear that commitments to greenhouse gas (GHG) reductions may undermine agricultural growth and food security. However, there may be considerable opportunities for investments in new GHG abatement technologies that may also offer new sources of investments with positive spill over effects for agriculture in terms of enhanced capacity and greater productivity. Such investments could well be financed by carbon offsets in developed countries, and could provide a win-win type of carbon offset. However, to reverse the negative attitude of developing countries towards adding agriculture in carbon offsets, there is a need for technical work to specify the carbon emitting patterns of various agricultural production systems.

The market for carbon offsets is still at it infancy and there are lot of unknowns as to its implication and its ramifications. In the United States of America, as there is a push to create a separate source of carbon allowances for farmers, who can opt for eco-friendly farming techniques or plant trees and would earn so-called offsets to sell alongside government permits on carbon markets. Such market is potentially huge given the scale of pollution coming from agriculture. Currently, the carbon-offsets market is at a pilot stage. At the Chicago Climate Exchange, a pilot program lets farmers supply credits for sale to companies, such as Ford Motor Co. and American Electric Power Co., which have agreed to voluntary emissions limits. Its sibling Chicago Climate Futures Exchange, in November 2008, began trading futures that can be used if a mandatory cap-and-trade law is enacted. Currently, U.S. legislation under proposals seek to subsidize emerging markets for environmental services, such as carbon sequestration, renewable energy production, and providing clean air, clean water, and wildlife habitat. If passed, such legislation will herald over time the emergence over time of a whole new industry based on carbon-offset system.

The implications for developing countries of these GHG reduction type programs whether incentivised by targeted subsidies or carbon offsets are not documented or understood. De Gorter (2009) argues that most of the mitigation potential in developing country agriculture will come from emission abatement activities resulting in changes in production practices and not in reducing fossil fuel consumption and output. Such changes can be facilitated with carbon offsets in the form of targeted subsidies for abatement activities. However, private agents cannot do it along, and public investments in R&D, extension services and technology transfer packages are required. De Gorter also argues for new financing mechanisms outside the current CDMs which, as currently designed, have not proved of limited use in developing country agriculture. Moreover, this may also call for rethinking domestic agricultural policy in developing countries, such as input subsidies by rechannelling public interventions into production practices that also lead to reduced emissions. Still large financial aid to developing countries may be required given the large investment required to finance R&D and new institutions to deliver the altered production practices.

*In summary, this paper arguse that while OECD farm support subsidies can be further reformed to return their negative distortionary effects on developing country agriculture, the latter can also be much more stimulated from actions developing countries can do themselves. This begins with a serious strategy for robust and sustained investments strategy for agriculture with for role for public, private and foreign direct investment. Also, improving agricultural productive capacity necessitates developing the infrastructure for input (seeds, fertilizer) supply and accessibility, and when necessary, promote effectively targeted input subsidies. Such investment strategy should also include the promotion of risk reduction and risk coping policies for poor producers. This includes market based safety nets designed as a supplement to other relevant domestic support measures.*

*Another area pregnant with potentially large flows of investments to developing countries (under largely unknown modalities) arises from the global efforts to tackle climate change and reduce GHG emissions. Such influx of investments could transform swats of developing country agriculture is they bring along new and improved technologies, more input use efficient and more productive. However, this is still largely a new area that requires further research and investigation. More work is needed at technical and institutional levels to understand how best to include developing countries in emerging carbon offset markets, and this could form a significant part of FAO technical work.*

*Finally, a new Doha Agreement would be highly desirable from developing countries perspective if it places significant ceilings on commodity-based distortionary domestic farm support and include major reductions in market access restrictions. Also, such an Agreement must allow developing countries sufficient flexibility, including a Special Safeguard and Special Products. These measures are necessary for many developing countries to successfully complete their agricultural transformation.*

## 3. SUMMARY. OPTIONS FOR NON-DISTORTING FARM SUPPORT

In the paper the following types of policies have been identified as possibly non-distorting while at the same time meeting some of the policy objectives that are prevalent in today's world.

**Encourage the further decoupling of farm policies in developed countries**. There is an overall tendency within OECD to move gradually to more decoupled forms of support and this should be encouraged. Overall, OECD commodity specific farm support has declined from over 80 percent in 1986 to about 50 percent in 2007. This reduces distortions and makes future reductions in support more politically feasible. It can also be justified as an exit strategy from farming for many developed country farmers.

**OECD countries could offer compensatory financing for developing country producers.** Given the continued support to OECD farmers, fairer trade can be achieved by compensating developing country producers for distorting (amber and blue box type) support accorded developed country farmers. One option is to agree that a certain percentage of farm subsidies in OECD countries be put into a global development fund to be distributed to eligible developing country (especially LDC) farmers along established criteria for eligibility, such as the estimated distorting effect on them from developed country policies. The funds could be used for projects to raise production, ensure sustainability of productive resources, agricultural research, and improvement of local human capital that is tied to agriculture.

**Promote decoupled policies to maintain agricultural production "reserve" in high income countries**. Such policies, which could include support for land set asides, support for technology and farm human capital skills, incentives to maintain set-aside land in production ready and environmentally sustainable condition, and other similar policies, could be a powerful alternative to physical and very expensive "commodity reserves" which are not only hard to organize, but also very questionable in their effectiveness.

**Use carbon offsets in developed countries to promote carbon reducing but at the same time productivity enhancing agricultural technologies and investments in developing countries**. Currently in most developing countries governments are not willing to face up to the issue of including agriculture in the environmental debate, for fear that only the negative GHG contributing part of their agriculture will be emphasized. However, there is considerable room for promoting investments and technologies in developing country agriculture that will both increase productivity as well as reduce GHGs. Such investments could well be financed by carbon offsets in developed countries, and could provide a win-win type of carbon offset. However, to reverse the negative attitude of developing countries towards including agriculture in carbon offsets, there is a need for technical work to specify the carbon emitting patterns of various agricultural production systems.

**Agricultural insurance in OECD should deal only with extreme and upredictable agricultural risks that cause market failures**; As OECD farm support shifts from commodity based to decoupled measures, farm incomes have become more variable, and safety nets in the form of risk mitigation measures, such as revenue or weather insurance are been increasingly relied upon to provide protection from unpredictable low farm incomes. Existing agricultural insurance schemes are inefficient, expensive, and distortive, as they entail high transaction costs and as they tend to increase the expected returns of covered products. In addition they crowd out private insurance companies. For insurance schemes to be non-distortive, they need to be more market based, for instance in the form of index based weather and price insurance, with payments depending on rather unusual and unpredictable events. In other words, agricultural insurance must concentrate on dealing with the so-called "market failure" part of agricultural risks, while leaving the other risks to be handled by the private market and farmers themselves. Hence more market-based agricultural crop insurance, that deals with market failures, must be encouraged as a way to providing non-distortive safety nets to OECD farmers.

**Lower market access restrictions imposed by OECD countries on agricultural imports from developing countries, especially LDCs.** Such restrictions in the form of tariff barriers, standards, phytosanitary restrictions, etc**.** have an important negative impact on developing countries. Exports from developing countries still face high import barriers, except for countries that benefit from preferential tariff access such as those benefiting from GSP (Plus), AGOA or EBA. Recent analyses show that the beneficial effects for third countries of a complete removal of the CAP and other OECD trade restrictions stem mainly from the tariff dismantling. Everything But Arms (EBA) type of trade policies of developed countries versus LDCs seem appropriate.

**Promote a Food Import Financing Facility (FIFF) to insure LIFDCs from sudden and adverse movements in their food import bills**. During last year's global food shock, many low income food deficit countries (LIFDCs) were unable to import enough food to maintain domestic consumption levels because of trade finance restrictions imposed by export financing institutions in developed countries. This problem is a recurring one and was supposed to be dealt with under the Marrakesh Decision of the Uruguay Round but was never tackled. The purpose of such a FIFF would be to provide additional trade financing to the agents of LIFDCs for the cost of **excess food import bills**, so as to maintain normal levels of quantities of imports in the face of price shocks, or to make it possible to import extra quantities in excess of normal commercial import requirements.

**Promote a market based and more automatic compensation scheme for negative agricultural export earnings variations for commodity dependent low income countries.** The problems of the earlier EU STABEX scheme as well as its successor the FLEX scheme are well known, and they are due to the ex-post nature of their compensatory structure. The same is true of the IMF CFF facility. In the meantime, the underlying problem facing low income commodity dependent economies has not diminished. The idea behind the new type of policy is to link commodity related compensatory payments to index based financial products, so that compensation can be made automatically and objectively.

**Promote public and private sector investment strategies.** This involves emphasis on public investments in various infrastructure and technology related areas of relevance to agriculture, as well as the promotion of public-private partnerships for the development of commodity value chains. Increased overall public investment must be combined with appropriate composition of such investments to promote growth. There is a need for appropriate guidelines for public sector investments in different groups of developing countries.

**Promote the use of effective market enhancing subsidies.** These may include policies to create input and output markets where none exist, policies to promote fertiliser and other input use as part of a wider growth strategy, policies to promote competition in input supply, policies to promote pro-poor growth and food security, etc. Such policies are considered domestic support policies, and flexibility in their use could be allowed for developing countries and LDCs in the WTO agreements.

**Use trade policies selectively to support and complement domestic investment programs**. The best policies to promote domestic agricultural investments are direct ones, targeted to the relevant sectors. Trade policies, however, should not undo or counter what domestic investment policies and strategies do. Hence policy space, perhaps in the form of tariff flexibility to allow for "development gaps", could be envisioned to allow developing countries to support domestic investments. In this context WTO may need to recognize and differentiate the developmental orientation of trade instruments in low income countries compared to the pure farm support nature of policies in developed countries.

**Promote risk reduction and risk coping policies in developing countries**. Developing countries' agriculture is much more exposed to various natural and market risks. For lack of other instruments and safety nets, much of DC producers' savings capacity is spent in self insurance. In addition they often become trapped in low return but low risk production activities. Policies to reduce the risks faced by low income farmers and to help such producers cope with negative shocks could be instrumental in unleashing their own savings potential and moving them out of their poverty trap. Market based safety nets could be a useful supplement to other relevant domestic support measures, but must be allowed under the WTO agreement.

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# CHALLENGES AND OPPORTUNITIES FOR AFRICAN AGRICULTURE AND FOOD SECURITY:
## HIGH FOOD PRICES, CLIMATE CHANGE, POPULATION GROWTH, AND HIV AND AIDS

**Hans P. Binswanger-Mkhize**[1]

## ABSTRACT

Over the past decade, economic and agricultural growth in sub-Saharan Africa (SSA) has resumed. The secular downward trend in agricultural prices ended in the early 1990s; growing incomes in Asia and Africa, combined with continued rapid population growth, are fueling food demand, which is expected to lead to a gradual upward trend in international real agricultural prices. For Africa the major agricultural growth opportunities will be in regional and domestic markets for food staples. Economic and agricultural growth have resumed despite continued high population, the AIDS crisis, and the onset of measurable climate change. Climate change will provide both challenges and opportunities, and countries need to strengthen their general capacities to deal with stresses and weather shocks in line with general agricultural development priorities. Population growth adds to the challenge of increasing per capita income and feeding Africa. It will also drive further agricultural intensification and in many place has led to improvements, rather than deterioration in the natural resource base. The fight against HIV and AIDS in rural areas is lagging badly and will need to be intensified via participatory approaches to prevention, expansion of HIV and AIDS treatment to rural areas, and massive improvements in rural safety nets. To seize the agricultural growth opportunities that derive from recent policy and price trends, SSA will have to support economic growth via continued sound macroeconomic policies, further improvements in the investment climate, and investments in infrastructure and institutions. More specifically in the agricultural sector, SSA will have to (i) further reduce agricultural dis-protection in countries and commodities that still practice it; (ii) reduce barriers to intra-regional trade in food and other agricultural commodities and properly finance the regional institutions that support regional trade, quality and phyto-sanitary controls, and other regional agricultural public goods; (iii) sharply increase domestic and regional funding of agricultural science, science education, and research; and thereby regain the technology agenda from the donors; and (iv) assist in the deepening of domestic markets and foster sharp improvements in smallholder services.

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## EXECUTIVE SUMMARY

After decades of decline of per capita food production, we are now in a period of new optimism about the prospects for Africa and for African agriculture. For Africa as a whole, economic growth was well above 5% until 2008, whereas for sub-Saharan Africa (SSA) it was above 5.5% (IMF, 2009). Agricultural growth in SSA has been above 3.5%, well above the population growth rate of about 2%. Armed conflicts are down to 5 from 15 in 2003. Although there are setbacks, such as the recent Kenya and Zimbabwe crises, democracy has advanced significantly. Sub-Saharan Africa (SSA) now has faster progress in its business environment than the Middle East and North Africa and Latin America (World Bank and IFC 2006). Africa is in the process of strengthening its regional and sub-regional institutions.

This paper documents the empirical evidence for the causes of the low economy-wide and agricultural growth rates, and for their subsequent recovery. It then goes on to review the evidence of the impacts which climate change, population growth and HIV and AIDS have had and are likely to have in the future on the agricultural and food sectors, as well as the challenges and selected opportunities they present. It then compares these challenges to other challenges faced by agriculture and food security and reviews the needed actions to overcome them. The executive summary provides the conclusions, but not the evidence, which is in the body of the paper.

The failure to grow as rapidly as the rest of the developing World has left a terrible legacy of poverty and hunger (Collier 2007; Ndulu et al. 2007; Binswanger-Mkhize and McCalla forthcoming). As a consequence SSA is the only continent in which poverty has increased in absolute and relative terms. Poverty and hunger are deepest in East, Southern and Central Africa, where AIDS prevalence rates are also much higher than in West Africa. It has made Africa more dependent on food imports, making it much more vulnerable than other regions to the recent food price shock. The failure to grow has retarded the demographic transition that has significantly lowered population growth rates elsewhere. As a consequence, Africa has not yet started to benefit from a population dividend associated with lower dependency rates. Low growth has aggravated the debt crisis and reduced domestic resources for infrastructure, agricultural development, health, education, and nutrition. It has aggravated the HIV and AIDS crisis. And finally it has made Africa less able to adapt to climate change. It is for this reason that this paper will first and foremost focus on growth in general, and agricultural growth in particular. The paper will analyze one by one the factors that caused the decline in growth, those that then led to the recovery, and the remaining challenges for the acceleration of growth.

The decline in growth rates were triggered by the oil and food crisis of the early 1970 and persisted well into the 1990s. The decline was primarily caused by poor macroeconomic management, overvalued exchange rates, high import tariffs that penalized the export sectors, and agricultural policies that penalized the sector. The highly adverse agricultural policy environment was aggravated by a steep decline in international agricultural prices from the early 1970s to the late 1980s, which combined with high agricultural protection and subsidies in OECD countries further reduced the profitability of agriculture. An overemphasis on state economic management via loss-making parastatal enterprises added to the fiscal crises and reduced the space for private sector involvement. By the early to mid 1990s, many of these adverse policies had been replaced by fiscal prudence, macroeconomic stability, a more open trade regime, and a more favorable private sector environment. Economies in general and agriculture in particular resumed their growth, starting with the most rapidly reforming countries. Debt relief in this decade provided further fiscal space.

The long term decline in real food prices ended in the 1990s, with the precise date depending on the commodity group and on the price deflator used. Since 2005 real food prices have exploded by more than 60 percent over their 1998-2000 level, only to lose about two thirds of that increase in the months until since July 2009. While nobody expects food prices to stay at such high levels, all models and experts agree that they will settle at significantly higher prices than in the last decade (FAO 2008). As a consequence, African agriculture is likely to become more profitable. Agriculture has returned as a priority on the International Development Agenda, of the African Union and NEPAD. The latter have developed the CAADP process that provides both a vision for agriculture and a process to develop national and regional agricultural development programs.

It is striking that the resumption of growth and agricultural growth was not caused by significant investments in infrastructure, the closing of the agricultural technology gap, or the provision of better services to smallholders. Aid volumes provided by OECD countries have not significantly increased, and even sharply declined for agriculture. Nor has the quality of aid provided improved. Business climates in Africa still rank low in international comparisons, despite the higher rates of improvement. Transport costs are still among the highest in the World. Electricity supplies are unreliable and costly. Financial sectors are under-developed, reaching only few clients, and savings rates remain much too low. Private input and output markets did not develop as fast as expected and farmers continue to be severely penalized by inadequate competition in these markets, and by higher input prices and lower farm gate prices than in other regions of the World. While some countries benefited from special trade preferences in US and European markets, these gains were limited because the developed countries continue to protect "sensitive" commodities, some of which would provide the greatest opportunities. Global trade talks have floundered again on questions of agricultural trade and little relief is in sight from reduced protection in OECD countries.

Growth also resumed despite continued high population, the AIDS crisis, and the onset of measurable climate change. In particular, earlier fears of HIV and AIDS induced food crises in countries such as Malawi have not materialized. Instead better rains and supportive fertilizer subsidies have led to an agricultural recovery in that country. That does of course not mean that high population growth, AIDS and climate change are negative factors for growth, only that their impact has not been severe enough to prevent the resumption of growth. And finally, while extremely high oil and mineral prices have helped net exporters of these commodities, growth has accelerated nearly as much in the net importing countries.

Higher world prices, combined with rapid demand growth associated with population growth, urbanization and income growth open the greatest opportunities for African farmers in domestic and regional markets: In these markets farmers compete at import parity prices rather than at the lower export parity prices, and they face lower phyto-sanitary and quality challenges than in overseas markets. Via import substitution they therefore have a major opportunity to re-conquer markets lost to imports in the previous 45 years. Undoubtedly farmers will also be benefiting from enhanced overseas market opportunities, especially in the longer run after developing their domestic and regional markets.

While the outlook for African growth and agricultural growth in general is positive, a number of countries such as Zimbabwe, Kenya and the Ivory Coast suffer from still unresolved political crises, and conflicts in the Sudan, Somalia and Northern Uganda continue. Other countries continue to progress in governance and policy reforms, and Zimbabwe continues to pursue all of the failed policies of the 1980s.

*Because so much policy change has already been done, further improvements in macro, trade and agricultural policies are unlikely to provide a major boost in growth rates. New sources of growth are urgently needed. Based on the analysis in their report, Ndulu et al. (2007) propose a medium-term strategy that hinges on taking action in four areas (characterized as the four "I's"): improving the* ***investment climate****; a big push toward closing the* ***infrastructure*** *gap with other regions of the world; a greater focus on* ***innovation*** *as the primary motor for productivity growth and enhanced competitiveness; and* ***institutional*** *and human capacity. And Collier (2007) suggests that much more needs to be done for the lagging bottom billion countries, on which aid should increasingly be concentrated. But aid will not be enough to assist these countries. It has to be combined with measures to reduce and recover from conflict, including prolonged military interventions, and support to the rapid rebuilding of essential state capacity.*

What are the challenges for rural areas, for reducing rural poverty and hunger? The task of this paper was to specifically address the challenges of climate change, population growth, and HIV and AIDS, so they are discussed first.

### Climate change

Very few people today doubt that man-made climate change is now occurring. SSA contributes the least to greenhouse gas emissions, yet is expected to be among the most negatively affected by climate change. Depending on whether carbon fertilization benefits materialize, the aggregate impact of climate change on African agriculture until the 2080-2100 period is estimated to be between 15 and 30 percent. To put these into quantitative perspective, an increase in the rate of total factor productivity of less than one-third a percentage point would be able to offset even the higher of these loss estimates.

For African farmers the adaptation challenges are obvious: They increase agronomic complexity and increase risks of shocks at the farm and community levels and imply additional changes in crops, cropping patterns, timing, agronomic practices, and seed needs. But the analysis of this papers shows that for particular African regions neither the specific nature nor the severity of the climate change impacts can yet be predicted with any degree of certainty. Therefore, despite several initiatives to do so country by country, it is not possible to plan specific measures of mitigation, such as the length of growing seasons of crops. Instead, in terms of adaptation in Africa, what is required is *strengthening of capacities of African agriculture and food systems to adapt to climate change*, via improved technology generation and adoption systems, more and better irrigation and drainage, better markets, and greater ability to import foods in bad years or on a year round basis, greater preparedness for extreme weather events, and better safety nets. *However, all these improvements are also most urgently needed even if there were no climate change. Climate change, therefore, does not generate a separate agenda for agricultural and rural development, only reinforcements of existing agendas. Adaptation to climate change needs to be mainstreamed into this general agenda.*

In terms of mitigation, public expenditures on mitigation should be subject to serious cost-benefit analysis, comparing the benefits of spending a lot of money on small reductions on $CO_2$, or the same or less money on more pressing current issues. This is a real trade off, and no-where is this more true than in SSA and its agriculture: SSA is the continent contributing the least to global warming. It has the most urgent economic and social problems that press on the current generation, and that will be less for future, more wealthy generations. Except for land use changes discussed below, the case for putting less emphasis on mitigation in SSA, and more on dealing with the pressing current needs, and with capacity building for future adaptation, is stronger here than anywhere else.

African agriculture, on the other hand, can take advantage of opportunities that climate change may present. Carbon trading, in exchange for offsetting mitigation measures, can increase income in rural areas. Achieving significant carbon mitigation in Africa can be achieved through land use change. The total potential saving still substantial and is achievable at a competitive cost. However, of the over 60 billion US dollars of carbon trades that have already been concluded globally, Africa has only benefited from about 3 percent. Few of these have involved agriculture, and half of the African carbon trades have been in South Africa. The institutional frameworks for carbon trading in land use change are poorly developed globally and in Africa. It is clear that to take advantage of these opportunities will require the building of appropriate policies and institutions at national, sub-regional and regional levels.

**Population growth**

The analysis in the paper shows clearly that a balanced view of the population challenge for African agriculture and food security stresses both opportunities and challenges:

Past population growth and high fertility rates lock in a considerable momentum of population growth that will lead to higher rural populations, extremely rapid urbanization, and high dependency rates, which in hard hit countries are accentuated by high adult mortality from HIV and AIDS. However, AIDS is not expected to lead to population declines in any country in Africa.

The rapid population growth is not only is a drag on growth, but also generates huge unemployment problems among youth; agricultural development should be seen as an opportunity to generate much more employment for rural youth and thereby help stem urbanization. While the demographic transition has barely begun in SSA, faster economic growth, higher female education, and a resumption of family programs could significantly accelerate it, and thereby create a population dividend for future economic and agricultural growth.

Out of the total land area in Africa, only a fraction is used for arable land. A FAO study has estimated the potential land area for rainfed crops with a total potential for the whole of Africa in 300 million hectares. To harness the enormous land reserves of the continent will require more labor and migration of populations from higher population density areas and areas with little or declining agricultural potential to the lower population density areas, where better quality agricultural land is available. Such migration would be greatly facilitated by regional integration that would allow for international labor movements. However, the land reserves cannot simply be harnessed by migration, but require enormous investments in infrastructure and technology. The expected higher agricultural price environment provides a major opportunity for such investments.

Rather than fueling land degradation, longitudinal studies have convincingly shown that population growth, market access and higher incomes can contribute to more sustainable use of agricultural land and other resources. It induces intensification, higher land investments, crop livestock integration, and more trees. If combined with better output and input markets, population growth leads to higher applications of organic matter and fertilizer, and these in turn can stem the nutrient mining.

The rhetoric of massive land degradation and desertification in Africa is poorly backed up by more than isolated studies and maps of erosion risks. Quantitative evidence is lacking. Where it occurs it is not caused by population growth, but rather associated with low payoffs to land and fertilizer investments, poor tenure security, and open access to pastures and forest areas. Local and national institutions to improve security of tenure and control open access are therefore important to prevent resource degradation.

The TerrAfrica program and the Alliance for and Green Revolution in African (AGRA) have put soil degradation at the center of their activities. Application of known soil conservation and improvement techniques is not as much a matter of more agricultural extension, as a change in underlying conditions of agricultural profitability, tenure security, and institutions to prevent open access.

Climate change, desertification and bio-diversity losses really come together in the local government arena, communities and on the farms, requiring management and adjustment capacities. Conventions in all three areas provide financing opportunities, including the Global Mechanism hosted by the International Fund for Agricultural Development (IFAD), a financing instrument for the Convention of Desertification.

### HIV and AIDS

The major impact of HIV and AIDS are the loss of human life and the enormous suffering of the patients and the families who experience AIDS deaths. As mentioned before, even in high prevalence countries of Eastern and Southern Africa, these deaths will not lead to a population decline. Impact estimates on economy-wide growth range from the benign to the alarming. In addition, the AIDS crisis has severely increased tuberculosis and malaria infections, making these diseases much more prevalent and dangerous. The diseases are aggravated by the growing crisis of multi-drug resistant tuberculosis, and increased resistance of malaria to common, inexpensive drugs.

Whatever these impacts of HIV and AIDS may be, they have, however, not prevented the resumption of growth even in the high income countries. Impacts on agricultural output growth are still poorly understood, but as mentioned before, the fears of HIV and AIDS famines have probably been exaggerated.

At the household level, HIV and AIDS morbidity and death can lead to distress sales of assets and therefore reduce capital stocks available to survivors. Both aggregate agricultural labor supply and labor demand are reduced, leading to little aggregate labor scarcity of wage rises. Impacts on the availability of labor of an AIDS death are often mitigated by the absorption of new adult household members, although this is not the case in numerous cases, where grandmothers or older children become household heads. Many households recover quickly in terms of agricultural output, but others suffer a persistent impact of low availability of land, labor, capital, and farming skills. It is for these households that agricultural interventions are the most necessary and useful to help their recovery.

Major counterintuitive findings are as follows: Better food intake and nutrition does little to reduce the risk of infection with the HIV and AIDS virus, nor does it significantly prolong life of untreated individuals beyond the modal number of 8.9 years after infection. Only anti-retroviral therapy can prolong life, by many years across the World and in Africa. In addition, not all orphans are experiencing lower food intake, nutrition, education and health than non-orphans. This is because African families place the orphans with those relatives better able to care for them. On the other hand, the above welfare indicators are worse for households that take care of more than one orphan, apparently because the burden is just too much. Since there are a rapidly growing number of such families in Africa, the social protection acquires even more urgency.

HIV and AIDS prevention, treatment and care and support are less well developed in rural areas than in urban areas, and even in urban areas there is far from universal access to these measures. The main challenge that HIV and AIDS pose for agriculture and rural development is therefore to ensure that these three components of the fight against HIV and AIDS achieve universal coverage. This is more difficult in rural than in urban areas, but not impossible. For example the WHO guidelines for HIV and AIDS treatment are specifically designed to make it possible to provide treatment even in areas that only have access to a health post managed by a nurse.

Each of the three major components of the fight against HIV and AIDS consists of several individual interventions. In many of them deep involvement of communities is necessary: Attitudes toward condoms and HIV stigma cannot be changed without community involvement. Adherence to AIDS treatment is difficult and requires family and community support. And care and support in rural areas have to be almost entirely managed by communities. Approaches to community involvement in the fight against HIV and AIDS in rural areas are well developed, but used insufficiently. A consequence is that community-driven agricultural and rural development programs must mainstream all three components of the fight against HIV and AIDS. It makes little sense, for example, to implement a land reform program only to see many of the beneficiaries succumb to AIDS or the associated tuberculosis and malaria.

### Key Challenges to Agricultural Growth, Rural Poverty and Hunger

Neither population growth nor climate change will present insurmountable challenges to agricultural development in Africa, if Africa seizes the opportunities it now has. And both provide opportunities. Reducing the death and suffering from HIV and AIDS requires generalization of prevention, treatment and care and support in rural areas, taking advantage of agriculture in the care and support area.

But there are other serious threats to the agricultural growth rate, and the reduction of poverty and hunger. This paper focuses on the most serious ones: the widening technology divide, slow development of input and output markets and the associated smallholder services, slow progress in regional integration, and inadequate safety nets to deal with extreme poverty, risks and fluctuations.

Agricultural growth in SSA is primarily a result of area expansion, rather than productivity growth in crops and livestock. The challenges of productivity growth are higher in SSA then in other Regions of the world: There are more different environments to deal with, more crop varieties, and more crop and livestock pests and diseases than elsewhere. There are no dominant farming systems that extend over very large areas such as irrigated rice and wheat in Asia. Irrigation infrastructure is poorly developed. And climate change will significantly add to the technology challenge. As a consequence of these factors, Africa is less able to borrow technology from other tropical countries, and technology transfers between regions in Africa are also constrained.

#### *The growing Technology Divide*

Rates of return to agricultural research have been almost as high as in other regions, however. And well above 25 percent of the cropped area now benefits from improved varieties and hybrid seeds. However, yield gains associated with high yielding varieties are much less than in other regions, owing to the heterogeneity of agriculture, the inadequate input and output markets, poor smallholder services, and poor infrastructure. As a consequence the use of irrigation, fertilizers and pesticides is much less than in other Regions, sharply limiting the yield gains.

Despite the much higher need for agricultural research, Africa invests significantly less than other regions. Its large public research system contains over 400 institutions, but they are small. The 3000 agricultural scientists in Africa are less well trained than those in other regions, and they have much fewer resources to work with. The agricultural science education system is similarly fragmented into 200 institutions, and poorly funded. It is therefore not clear where and expanded agricultural science force will come from. Ten of the CGIAR institutions are active in Africa and four are located in Africa. Their funding is, however, only one-tenth of the overall funding for agricultural research in Africa, and has been stagnating at that low level.

The limited research resources also seem to have been increasingly misallocated. Given the heterogeneity, the poor borrowing opportunities, and the enormous challenges from pest, diseases and water stress, basic innovations at the science level are urgently needed to in a wide variety of crops and livestock diseases. Yet the proportion of research going to basic sciences has been declining in national and international research systems alike. Instead the resources have gone to agronomic and farming systems and environmental research that has little record of high rates of return. The African Challenge program continues the same unfortunate trend. Scarce scientific resources have also been diverted to implementation of programs, rather than research. While Africa has created not less than four regional centers for biotechnology, these remain severely underfunded. The blame for these factors may lie primarily with donors impatient for immediate results, or distracted by donor fashions. Despite their commitments to the CAADP agricultural priorities, national governments have also not significantly increased their funding for agricultural research in general or biotechnology in particular. They also have invested little in biotechnology capacity, probably for political reasons. In the meantime India, China and Brazil are sharply increasing their investments in biotech research.

There is some relief in sight. AGRA intends to fund the training of 1000 plant breeders. However, unless they can be posted in better funded institutions, the best of them will be lost to emigration. Private sector technology research has grown considerably, albeit less than in Asia and Latin America. However, unless the science base improves, the gains from conventional breeding in the public and private sectors may be insufficient to close the growing technology divide. The Bill and Melinda Gates Foundation, a founding member of AGRA, has is also invested in basic research in a number of crops, but given the enormous needs, the funding remains inadequate. There is therefore little hope that the crisis of the growing technology divide will see any rapid solution, unless African governments muster the political will to sharply increase the necessary funding.

### *Smallholder services and input and output markets*

Improvements in technology will continue to lead to lower productivity gains, if services, input and output markets are not significantly improved. Rural finance is also insufficiently developed. Farmers' organizations have made a lot of progress, but are still not able to provide much of the needed capacity. If the smallholder services, rural finance, and markets were improved, however, a number of problems will be closer to a solution: Farm profit and investments will increase, nutrition depletion will be reduced, and food insecurity associated with poor markets will be reduced. The re-conquest of domestic and regional markets will then also be closer at hand. Again, relying on donor finance for these improvements will not be sufficient to solve these problems. Political will on the part of African governments is needed to provide the necessary finance.

### *Safety nets*

While emergency relief is relatively well developed in SSA, safety nets for the very poor are not. This is again in sharp contrast to India and China. For example, less than 1 in 100 orphans receives any kind of assistance in SSA (other than South Africa). While South Africa has a number of conditional grants programs for the aged, children, and the disabled, few other SSA countries are experimenting with them. Support to traditional safety net mechanisms in rural communities is conspicuous by its absence. And few employment generation programs have more than spotty coverage.

But the need for safety nets will not be reduced by growth or agricultural growth. Such growth tends to bypass the very poor and destitute. The population of old people without family support will go up with population growth and improving incomes and health. Climate change, HIV and AIDS, malaria and tuberculosis, and the growing orphan crisis require better safety nets. Growth is increasing the fiscal space of African governments, and they need to take advantage of it to improve the safety nets.

### *The imperative of Regional Cooperation in agriculture*

Throughout this paper many critical issues were encountered that can best be, or only, solved by regional action, and more are yet to come; lets recall a sampling:

- Small countries dominate the African scene often lacking financial capacity for public goods investments;
- Small land locked countries generally do worse and depend on regional integration to be able to do better
- Expanded regional trade in agriculture and food products is good for growth, farmer's income and regional food security; the short run management challenges of the current food price spike and the long run opportunities arising from prices that are expected to settle at higher than past levels only

add to this imperative

- Expanded regional trade and food security will be helped by the harmonization of standards and sanitary measures, and sub-regional and regional capacities to implement them;
- Freer borders and internal infrastructure should encourage private sectors traders;
- For small countries, regional infrastructure – roads, communications, ports – is critical for access to each others and external markets;
- Reversing land degradation and desertification and preserving biodiversity require trans- boundary collective action;
- Managing crucial, but under threat, forestry and fisheries resources must be approached on a transnational basis;
- Defense against plant and animal disease epidemics require collective responses at sub-regional and regional levels;
- Success in agriculture crucially depends on indigenous scientific capacity to generate new technology. Given the capacities of small and poor countries, this is far better done on a regional or sub regional basis: FARA and the SRO's are on the right track, but the effort needs to be greatly expanded;
- Biotechnology research is expensive. It also requires a large critical mass of researchers. Therefore two or three regional institutes is far superior to 48 or 24 underfunded, under resourced national institutions;
- Indigenous scientific capacity requires trained people, again better done by regional institutions which have critical mass and necessary financial support;
- Regional approaches to rural financial architecture may increase potential deposits and loanable funds and spread risk;

These examples hopefully are enough to illustrate that the potential for regional approaches and an overall regional strategy for rural Africa are significant. In most of these areas institutional development programs have been created. Yet they remain massively underfunded. The main reason for this is that the regional efforts produce regional and sub-regional public goods, and therefore their financing is subject to the familiar free rider problem of financing public goods. Except the largest countries which have an incentive to supply themselves with these regional public goods, countries will seek to benefit from the investment of others. Better coordination of funding by African countries, as well as external co-finance, could help overcome the underfunding. But *donor finance remains both insufficient and unreliable for the task. The African Union, via the CAADP, the Economic Commission for Africa, and African Development Bank need to coordinate these efforts.*

## Conclusions

African agriculture today faces a context of general economic growth in Africa, and in the medium term a brighter market outlook in international, regional and domestic markets than anytime in the last 40 to 50 years. Both macro-economic and sector policies are more favorable. In most countries the institutional environment has also given local governments, communities and the private sector much more opportunities than in the past. And business climates are improving, albeit from a very low level. The smallholder-dominated agricultural sectors of Africa have already responded in terms of a significantly higher growth rate.

Improved market opportunities will arise in traditional as well as non-traditional agricultural exports and they need to be seized. At the same time domestic and regional markets will present the most promising area for medium to long term agricultural growth. That means that small farmers, despite the supermarket revolution and rising international quality standards, will be well placed to seize them.

While climate change is likely to affect most regions in Africa negatively, it will also open new opportunities in some regions where rainfall and other climate parameters will improve. Other opportunities arise from the possibility of carbon trade once the instruments for trading via land use commitments and changes are better developed. In the aggregate, the impact on African agriculture will undoubtedly be negative, but climate models are not yet sufficiently well developed for Africa to predict what will happen with sufficient certainty to engage in detailed planning. As a consequence, climate change should be mainstreamed into the general agricultural and risk mitigation agendas. In particular much better capacities for agricultural technology development are needed.

Population growth is not yet slowing sufficiently fast to provide for a population dividend. At the same time the evidence for a generalized negative impact of population growth on agriculture is lacking, and instead in many areas population growth, combined with good market access has led to beneficial agricultural intensification.

HIV and AIDS has led to an enormous human tragedy and a reduction in growth prospects in hard hit countries. Agriculture and food interventions can help in mitigate the impact in rural areas. But neither prevention nor treatment programs have yet been scaled up adequately in rural areas, despite the fact that how to do that is well known, and scaling up of these interventions remains the most pressing issue.

The most neglected aspect of the agricultural agenda in Africa has been agricultural technology, and as a consequence the continent faces a growing technology divide. The continent has a large number of agricultural scientists, research institutions, and agricultural education and science education establishment. But these are mostly too small, donor dependent and underfunded. As a consequence Africa is not only lagging badly in traditional approaches to plant breeding and animal disease control, but is at great risk of missing the boat in the biotechnology revolution. Unless Africa, like China, India and Brazil, starts investing more of its own resources into agricultural science, science education and research, the huge existing technology divide will only deepen.

The agenda for action arising from the analysis of this paper is not new. The four most important among them are as follows:

1. Avoid backsliding on economy-wide and agricultural policies and further reduce agricultural disprotection in countries and commodities that still practice it.
2. Reduce barriers to intra-regional trade in food and other agricultural commodities and properly finance the regional institutions that support regional trade, quality and phytosanitary controls, and other regional agricultural public goods and services.
3. Sharply increase domestic and regional funding of agricultural science, science education, and research, and the associated centers of excellence; and thereby regain the technology agenda from the donors and pull them along in increasing their funding of priority areas.
4. Assist in the deepening of domestic markets and foster sharp improvements in smallholder services

## INTRODUCTION

Most of the World's 2.1 billion people who live on less than 2 dollars a day live in rural areas and depend on agriculture for their livelihood. The number of rural poor has increased in Africa and South Asia, and reduced in East Asia and the Pacific. The World Development Report (WDR) of 2008 summarizes an extremely large literature which demonstrates the enormous power of agricultural growth for poverty reduction. Over the past 10 years global poverty with a 2 dollar a day poverty line declined by 8.7 percent in absolute numbers. This decline was caused *entirely by rural poverty reduction, with agriculture as the main source of growth.* At the same time urban poverty has increased. *Migration is not the main instrument for rural (and global) poverty reduction. Improved rural conditions are the main cause.*

The secular decline of food prices came to an end in the 1990s, with the précised date depending on the commodity group and on the price deflator used. Since the middle of this decade real food prices started to rise and spiked in early 2008 at about a 60 percent higher average level than in the early years of this century. By July 2009 they had lost at least two thirds of the price gain and have settled at a somewhat higher level than in the early 1990s. Most models and experts agree that food prices will remain at higher real levels than in the last decade (FAO 2008) and may even rise over the next few decades. For this and other reasons, agriculture has returned as a priority on the International Development Agenda.

As Johnston and Mellor (1961) showed nearly 50 years ago, agricultural growth reduces rural poverty:

1. By raising agricultural profits and labor income
2. By raising rural non-farm profits, employment and labor income via linkage effects
3. By causing lower prices of (non-tradable) foods, especially beneficial for the poor
4. Lower food prices reduce urban real wages and accelerate urban growth
5. Tightening urban and rural labor markets raise unskilled wages economy-wide.

The WDR divides developing countries into *urbanizing countries* mostly in Latin America, (but also South Africa) with 255 million people, *transforming countries* mainly in East Asia and the Middle East and North Africa (MENA) with about 2.2 billion rural people, and *agricultural countries*, mostly in sub-Saharan Africa (SSA), with 417 million rural people. It is in the agricultural countries, most of which are now in SSA, in which agriculture can contribute most to poverty reduction; but it is also in these countries in which it has lagged the most and confronts the biggest barriers to growth.

In Africa the impact of growth on poverty reduction is well illustrated by eight SSA countries that have seen per capita growth rates of 2.9 percent on average in the 1990s and have reduced poverty at an annual rate of 1.5 percent during the period (Ndulu et al. 2007). On the other hand, poverty in stagnating countries has increased. Agricultural growth has a much more direct impact on hunger than general economic growth: Pingali et al. 2007 have shown that by and large the countries with faster agricultural growth have made more progress against hunger. Hunger has therefore significantly declined in West Africa, and it has increased significantly in the conflict or coup countries. Countries like Liberia, Sierra Leone, Comoros, Burundi, Guinea Bissau, and most dramatically the Democratic Republic of the Congo (DRC) have neither seen economy-wide or agricultural growth.

FAO has analyzed in great detail the reasons and impacts for the higher international food prices that have shocked the World since 2005, and especially in the past two years (FAO 2008). In the short run these have very negative impacts on the balance of payments, especially in East and Southern Africa, and significantly increase the number of people in poverty and the depth of poverty of those already in it. These impacts provide many policy challenges for African countries, especially for those who are not petroleum or mineral exporters. On the other hand, they provide enormous opportunities for Africa which, along with Latin America, has the greatest reserves of arable land. The rising international prices provide especially good opportunities in domestic and regional markets where Africa can substitute more easily for the now more costly imports. Therefore this paper will pay great attention to these rising market and agricultural growth opportunities.

The outline and some major messages of this paper therefore are as follows: Section 1 will look at past economy-wide and agricultural growth and analyze the factors that slowed it down, and then contributed to the striking recent turnaround. It will also look at the remaining policy and broad program agendas for further accelerating these growth rates. Section 2 will quickly review the short term challenges arising from the recent price explosion in food prices, as well as the emerging market opportunities for African agriculture. Section three on climate change will briefly summarize what we know, and what we still do not know about climate change and its future impact on agriculture in Africa. It will show that for many regions, science still provides little basis for planning specific adaptations to climate change. The section will therefore propose to integrate it into broad agricultural development and risk mitigation strategies. The section will emphasize that improvements in Africa's science and technology capacities and irrigation infrastructure that are needed for the growth agenda are also critical for dealing with climate change. If these were in place, the challenges of climate change would not be as daunting as it now appears.

Section 4 will deal with population growth in Africa. If economic growth rates can be maintained or further accelerated, the high population growth rate of SSA will come down as it has in other parts of the world. This will lead to a population dividend in terms of lower dependency and higher labor force participation rates that will be helpful for growth. The section also discusses the evidence that population growth is only a threat to natural resources if it is associated with open access; and it will show with African examples that agricultural intensification is usually associated with improved natural resources management as well as increased agricultural productivity. It will then discuss the agenda for natural resources management that arises from these insights. Section 5 deals with the economic and agricultural impact of HIV and AIDS. Agricultural and food interventions are helpful in dealing with the consequences of AIDS on affected households, but provide little leverage for reducing infection rates or prolonging the life of those infected. As a consequence the fight against rural HIV and AIDS has to use classic prevention and treatment approaches which are still lagging much behind. The section then suggests how to better design rural prevention and treatment programs. Section 6 deals with the Key challenges of Agricultural Growth, including subsection 6.1 on the growing technology divide that is probably the biggest threat to African agricultural growth and food security in the coming decades and that most urgently needs to be reversed. Other subsections deal with smallholder services, safety nets, and the imperative of Regional cooperation. Section 8 pulls together the conclusions.

## ECONOMY-WIDE AND AGRICULTURAL GROWTH IN AFRICA

### Fostering Economy-wide Growth

This section summarizes key findings from a large review of growth research in Africa carried out by Ndulu et al. (2007) and from Collier's (2007) book on the "Bottom Billion". The factors analyzed are by and large the same factors that held back agricultural growth, but we will discuss agriculture specific factors below. Per capita GDP growth in 41 sub-Saharan African countries for which data for the full 45-year period are available amounted to only 0.5 per cent, compared to 3 per cent in 57 countries in the rest of the developing regions, including North Africa. Growth performance has been quite diverse: 6 of 47 sub-Saharan African countries have more than tripled their per capita incomes between 1960 and 2005, 9 countries' per capita incomes are at the same level as when they started or below, and the remaining 32 have seen modest growth in per capita income, but not enough to make a significant dent in poverty levels.

The prolonged period of economic decline between 1975 and 1994 started with shocks on energy and tropical commodity markets and ended with a wave of democratic reforms between 1989 and 1994. In 1994-2004, there was more rapid per capita income growth, with 20 countries expanding more quickly than the average rate for the rest of the developing world. Entry into this high-growth club was associated either with natural-resource exploitation (Angola,Chad, Equatorial Guinea and the Sudan), or with strong reform movements (Benin, Ethiopia, Ghana, Malawi, Mali, Mozambique, Senegal and the United Republic of Tanzania). Economic growth further accelerated in all of Africa between 2004 and 2006, thanks to strong global economic growth and higher raw material and energy prices (ECA, 2007). In 2007, economic growth in sub- Saharan Africa reached 6.1 per cent.

How will the current economic crisis affect growth prospects for Africa? In 2007, world real GDP grew 5.2%, which translates into a 4.2% growth in per capita economic output. World output growth then declined to 3.2% in 2008 and is projected to decline at a -1.9% rate in 2009. The IMF then projects a rebound to 1.9%

and 4.3%, respectively, in 2010 and 2011. This means that global per capita output is projected to decline about 2.9% for the first time in decades, suggesting perhaps a negative change in global food demand in 2009. However, the decline in output is concentrated in the advanced economies, where income elasticity of food demand is very low. For the emergent and developing economies, where income elasticity of demand is higher on account of their lower income, the growth rate for 2009, 2010, and 2011 is projected at 1.6%, 4.0%, and 6.1%, respectively. They expected to be less hard hit by the global economic crisis, and their rising income may offset declines in food demand elsewhere in 2009 and add a positive trend to global food demand thereafter.

For Africa as a whole as well as for sub-Saharan Africa, the projected growth trends in output are similar to those for emerging and developing economies. It is particularly noteworthy that the output growth in sub-Saharan Africa in 2009, 2010, and 2011 is expected to be about 1.7%, 3.9%, and 4.5%, respectively. Since population growth is about 2% in SSA, the per capita income is only expected to decline marginally in 2009, suggesting that even in SSA, food demand may resume its growth fairly soon.

What explains the slow growth of Africa since 1960? Over the long haul, slightly less than one half of the lower growth in Africa relative to the rest of the developing World is associated with lower growth of physical capital, and slightly more than half with lower productivity growth. The share of investment in GDP has been only about half as high as elsewhere, and for a given investment, Africa has only achieved about two-thirds of the productivity growth.

The over 90 percent of SSA that lie between the Tropics suffer from much higher incidences of diseases that impact negatively on life expectancy, human capital and labor force participation. SSA has 48 small economies with a median income of only 3 billion US dollars. Forty percent of the population lives in landlocked countries, as against only 7.5 percent in other developing countries. Resource-rich landlocked countries did better than their resource-poor land-locked counterparts, especially in the 1970s and since 2000. Coastal resource-poor and coastal resource-rich countries did about the same over the long haul. Oil revenues are still poorly invested, and the recent rate of growth of the African countries benefiting from the oil bonanza has not been higher than that of the other African countries that suffer from the higher oil import costs.

The transport costs of landlocked countries depend less on distance, but on how much their neighbors had spent on transport infrastructure. To increase their chances, these countries need to focus on their own and their neighbor's transport infrastructure, including transport to the sea; on regional integration, and on reducing external trade barriers of their entire region. They must be interested in good economic policies of their neighbors. And, based on the analysis in this paper, growing urban, sub-regional and international markets can provide many opportunities for their agriculture (Box 1).

Conflicts have had huge costs: The proportion of Africa's population in conflict reached a peak near 60 percent in 1984 and another near close to 50 percent in the early 1990s. Conflict therefore was a more important determinant of the collapse of growth in the 1980s than usually recognized. (Ndulu et al. 2007). Collier (2007) shows that civil war is more likely where income is low, stagnates, or declines; in countries dependent on oil, diamonds, and other primary exports; but interestingly not where inequality is high. Civil wars last ten times as long as international wars (which last an average of six months). Once they are over, they are alarmingly likely to restart. Civil wars reduce economic growth on average by 2.3 percent. They sharply increase disease incidence. The end of civil war ushers in a boom in homicides. As a consequence of these factors, nearly half of all costs arise after the war is over. These costs spill over to neighboring countries and the rest of the world. Overall cost per civil war is estimated at 64 billion US dollars. Fortunately since 2000 conflicts ended in Angola, Sierra Leone, Liberia, and Southern Sudan. Conflicts in which a warring party was the government declined from 15 in 2003 to 5 today.

**Box 1: Are poor agroclimatic conditions and landlockedness un-surmountable hurdles to agricultural growth?**

Some of the past successes in commercialization in sub-Saharan Africa depended on agro-ecological conditions that were "ideal" for cocoa, tea, coffee, sugar and some other commodities. In some of these (e.g. tea and coffee), the market pays high quality differentials and the desired quality attributes can only be obtained where particular growing requirements are fulfilled. Therefore the global players (either traders or processors) have to access supplies from certain African countries in order to be able to satisfy their customers. Success in these commodities therefore has taken place despite the fact that many of the best regions were landlocked and remote. On the other hand, ideal agricultural conditions are not sufficient for success, as the example of the slow growing Zambian sugar sector shows, which enjoys some of the best growing conditions in the World. While there is a major sugar factory in Zambia, it has been unable to export sugar except into the protected European market. Other success stories in Africa, such as cotton and cassava in West Africa, occurred under favorable, but not ideal, climatic and soil conditions. They depend on highly labor intensive production processes that are difficult to mechanize and therefore benefited from low labor cost in Africa (Poulton, et al. 2006).

Beyond Africa, agricultural success was achieved in a spectacular manner in landlocked areas of at best moderate agro climatic potential and little irrigation in the Cerrado of Brazil and in North East Thailand. Since the 1960s, when African Agriculture declined or stagnated, these Regions became World class competitors in soybeans, cotton, maize, rice and beef (Cerrado) and cassava products, rice and sugar (Thailand). An in depth analysis of their success with comparisons to African countries can be found on World Bank (2008). Clearly, neither agroclimate nor geographic locations are complete determinants of destiny.

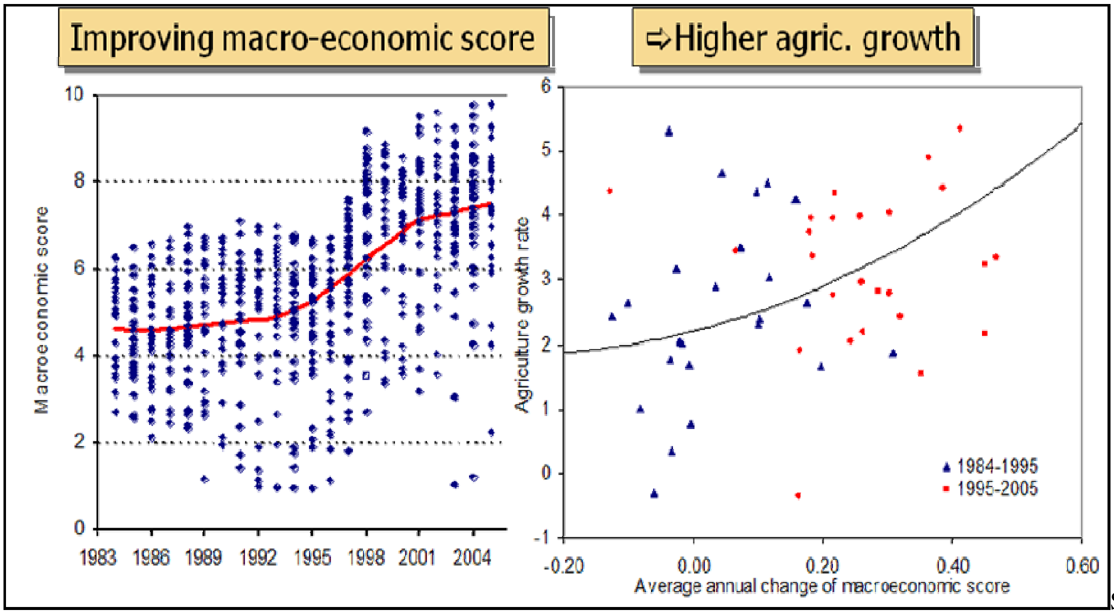
Natural resources contribute to the risk of civil war. Paradoxically, even at peace natural resource exports reduce growth. The "resource curse" arises from "Dutch Disease," the fact that resource exports lead to an appreciation of the exchange rate that makes domestic products uncompetitive in international markets as exports or as import substitutes. Sharp price fluctuations of the natural resources also lead to a boom and bust cycle. But resources also mess up politics by making it easy to finance patronage politics and reducing the restraints on political power that are so important for a functioning democracy: an independent central bank, judiciary and press, financial transparency, competitive bidding and the likes.

Collier (2007) shows that three quarters of the bottom billion countries have suffered from prolonged periods of poor governance and poor policies. These countries are not able to provide essential services required for growth. Resources get eaten up in corruption. Poor governance and poor policies create a trap because powerful vested interest benefit from them and oppose reforms. Failing states have stayed in their trap for a very long time over which huge costs accumulate: The cumulative cost of a failing state to itself and to its neighbors is about 100 billion US dollars. The benefits of helping turn around a failing state are therefore enormous (Collier 2007).

Controlling for differences in opportunities, differences in policy contribute between 25 and 50 percent of the difference in growth performance between SSA and the rest of the developing world (Ndulu et al. 2007). Greater integration in the world economy consistently is associated with higher growth performance. Fortunately policies have significantly improved over the last decade: unweighted consumer price inflation sharply fell within a decade, from 27 percent in 1995, to about 6 percent by 2004. "In a median SSA country, government spending as a proportion of GDP also fell sharply in the past decade, as it has in other developing countries in the world, and the average fiscal deficit was halved to 2 percent of GDP by 2000. Except in a few countries, black market exchange rate premiums now average just 4 percent. Through unilateral trade reforms, SSA countries have also compressed tariff rates; the average rate is currently 15 percent. As a consequence of the major policy reforms initiated in the continent since 1990, growth has resumed, and the impact of poor policies on growth may have waned" (Ndulu et al. 2007).

The improvements in general economic policies have not only contributed to economy-wide growth but have also accelerated agricultural growth, as Figure 1 shows.

**Figure 1: Macro-economic conditions and growth**




Source: World Bank (2007)

Other factors that have contributed to low growth are the following:

- In addition to low road densities, transport costs in SSA can reach as high as 77 percent of the value of exports (ECA 2004).
- A serious problem in Africa is the extractions and bribes imposed by the police and others at border posts and road blocks. "Along the West African road corridors linking the ports of Abidjan, Accra, Cotonu, Dakar and Lomé to Burkina Faso, Mali, and Niger, truckers paid 322 million US dollars in undue costs at police customs and gendarmerie checkpoints in 1997." (ECA 2005).
- Energy costs are higher and power outages are more frequent than in any other region of the World, and in particular compared to China.
- While Africa has made significant improvements in basic education, progress in skills development has been distressingly slow. Basic health care is very poor.
- SSA financial sectors are the least developed in the world. The median spread of interest rates is 13 percent in SSA as against between 5 and 10 percent for the other developing regions. Access by small firms is poor and collateral requirements are very high (Ndulu et al. 2007).
- South and East Asia have savings rates of around 20 percent compared to a mere 9 percent in SSA. Micro-finance institutions have only managed to mobilize a small pool of savings, have limited coverage and narrow areas of operations.

Based on the analysis in the report, Ndulu et al. (2007) propose a medium-term strategy that hinges on taking action in four areas (characterized as the four "I's"): improving the **investment climate**; a big push toward closing the **infrastructure** gap with other regions of the world; a greater focus on **innovation** as the primary motor for productivity growth and enhanced competitiveness; and **institutional** and human capacity. And Collier (2007) suggests that aid should increasingly be concentrated on bottom billion countries. But aid will not be enough to assist these countries. It has to be combined with measures to reduce and recover from conflict, including prolonged military interventions, and support to the rapid rebuilding of essential state capacity.

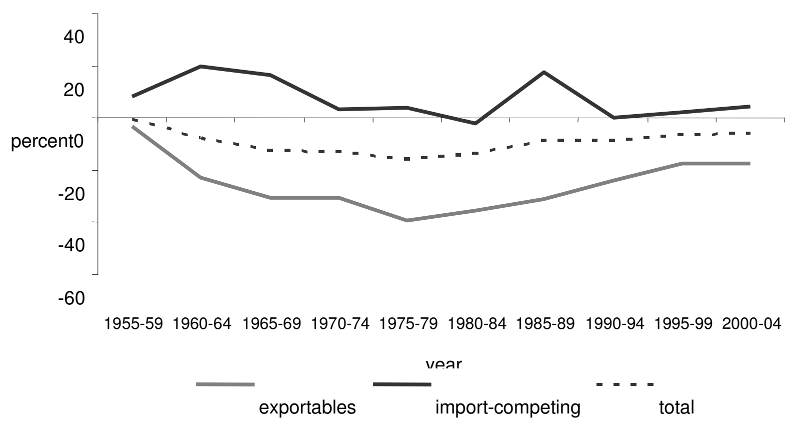
### Improving Agricultural Policies

Adverse policies of developed countries have been widely discussed and documented, and unfortunately have not much improved over the past two decades (World Bank 2007). They are therefore not further discussed here except to stress again that African agriculture stands to gain the most from multilateral trade reform rather than bilateral agreements (Anderson and Martin 2006). Moreover, in the absence of a breakthrough in the Doha round of trade negotiations, China and India could follow the developed world, Korea and Taiwan in protecting their agriculture to close the rising urban-rural income gap. This would close the major future export opportunity for African agriculture. African countries therefore have become active participants in the trade negotiations.

After the end of colonization, African countries started to discriminate sharply against agriculture via overvalued exchange rates, industrial protection, and direct agricultural taxation. A major study now has measured the combined effects of these three interventions on the net rate of agricultural assistance and compares them across the developing and developed world (Anderson and Masters, 2009). A negative rate of protection is in fact the rate of taxation. This is sometimes called *dis-protection*. As shown in Figure 2, for Africa as a whole, the net protection rates have improved from about –20% in 1975–1979 to less than –10% in the first half of the present decade.

However, the dis-protection of agriculture in Africa has to be compared to the trends in protection in the rest of the World. These shows that Africa still lags far behind other developing regions in improving its agricultural incentives regimes: Asia changed from being a net dis-protector of agriculture until around 1960 to a net protector of agriculture at rather high levels of between 20% and 25% since the second half of the 1980s. The same protection levels are also now applied in Eastern Europe and Central Asia. Similarly, Latin America, since the mid-1980s, is protecting its agriculture at a rate of about 5%. The average of the developed world, protection rates remain at close to 40%.

**Figure 2: Nominal rates of assistance to exportable, import-competing, and all agricultural products, African region, 1955–2004.**[2]



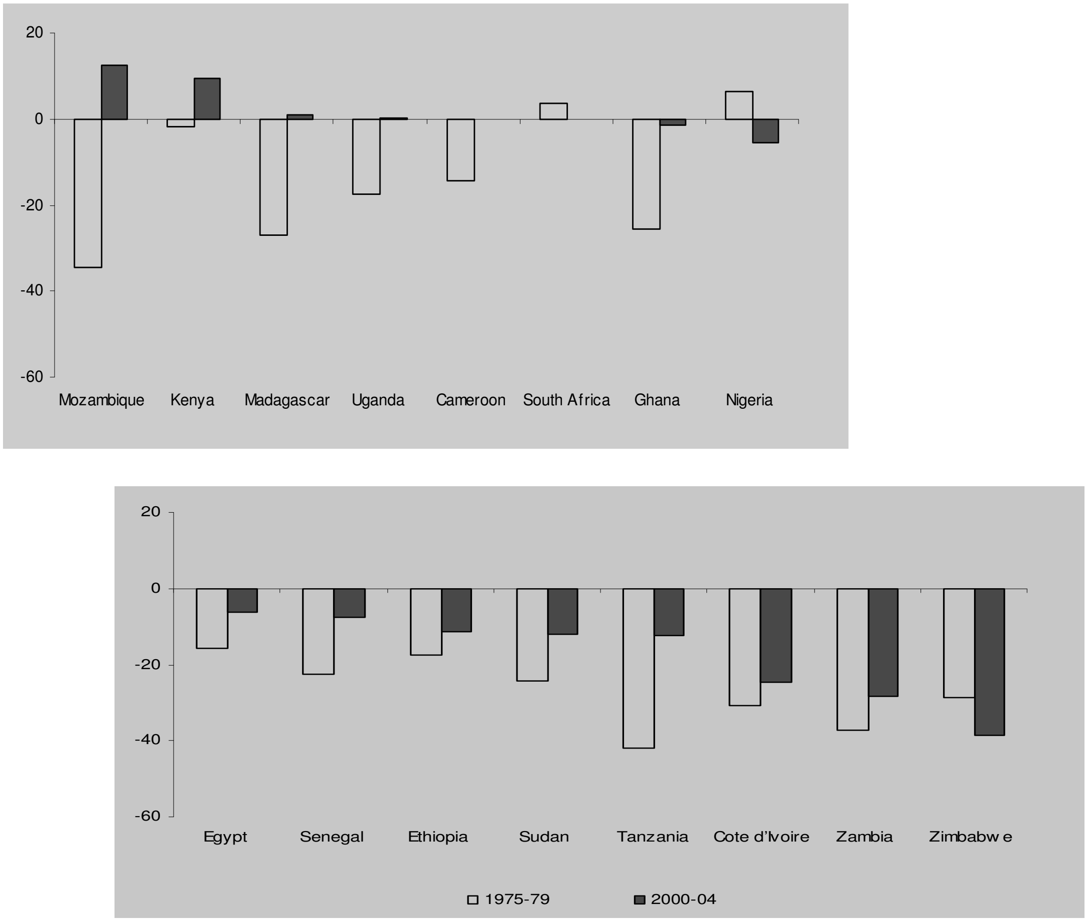

Source: Anderson and Masters (2009).

As Figure 2 shows, the antitrade bias against agriculture was concentrated on exportable commodities, which in the late 1970s were taxed at around 40%, whereas importables were almost always slightly protected. Although dis-protection overall is now less than 10% in Africa, it remains at almost 20% for the exportables.

Within SSA, agricultural taxation remains the most severe in Zimbabwe, the Ivory Coast, Zambia, and Tanzania (Figure 3). The greatest improvements since the first half of the 1980s were made in Mozambique, Kenya, Madagascar, Uganda, and Cameroon, where nominal rates of assistance are now positive or zero. In Egypt, the only North African country for which data are available, the NRA also remains close to –10%.

[2] Unweighted average across 16 countries.

**Figure 3: Nominal rates of assistance to agriculture in Africa by country (%), 1975–1979 and 2000–2004.**[3]

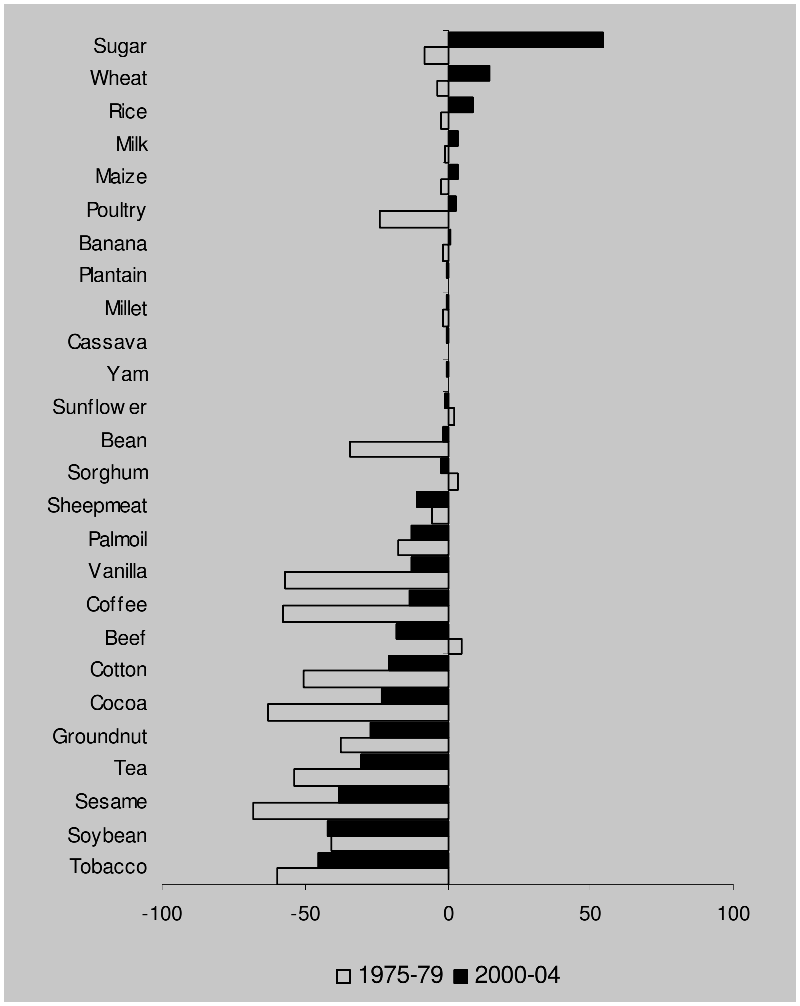



Sources: Anderson and Masters (2009).

Among agricultural commodities in Africa (except for South Africa), the nominal rates of assistance (NRA) across Africa for tobacco, soybeans, groundnuts, cocoa, cotton beans, beef, tea and coffee remanined at between -45 % (for tobacco) and - 15% for coffee (Figure 4). Clearly, across commodities and across countries there remain important opportunities for improvement in the incentive regime of SSA agriculture.

[3] Ethiopia data for the first period refer to 1981–1984; 1975–1979 data are unavailable.

**Figure 4: Nominal rates of assistance across commodities (%), 1975–2004.**[4]




Source: Anderson and Masters (2009).

In terms of Africa's own agricultural trade policies, five conclusions stand out:

- On balance, protection rates (or more precisely, nominal rates of assistance to agriculture) are no longer negative; they remain below –10% in Ethiopia, Sudan, Tanzania, Zambia, Côte d'Ivoire, and Zimbabwe.
- Taxation is still concentrated on exportable commodities. However, from taxing them at extremely high rates in the 1970s and 1980s, Africa has steadily improved its incentives regime. On average it is now less than 10%. However, taxation levels of a number of individual exportable commodities remain alarmingly high.
- Despite the improvements in incentives, African farmers still face the worst agricultural incentives in the world. This is first because only Europe has reduced its nominal rates of assistance to agriculture, whereas both the United States and, especially, Japan have increased them. Second, the other developing regions have moved from disprotecting agriculture to protecting their agriculture, in the case of Asia at a level that is now getting closer to the average of the developed world.
- Progress is being made in terms of regional integration across all subregions of SSA, but agricultural incentives also still suffer from barriers to interregional trade and poor phytosanitary capacities.
- Though improving, the business climates in most countries still remain far worse than in other developing countries, holding back private sector activities upstream and downstream from the farm. There has been

[4] Unweighted average across 21 countries.

significant progress in incentivers' regimes, but if countries in SSA want to compete better in domestic, regional, and international markets and benefit from the likely rising trend in international agricultural prices, they must move aggressively to eliminate export taxation of agriculture and remaining barriers to regional trade.

**Improving the Institutional Environment for Agriculture and Rural Development (ARD)**

In 1980, in a typical country in Africa, a young rural women (or man) who wanted to help develop her community, found herself almost completely disempowered. Three of the five pillars of the institutional environment, which are discussed below, were poorly developed: The first pillar, the private sector, was largely confined to small scale farming and the informal sector. Much of the marketing, input supply and agro-processing was in the hands of parastatal enterprises. The second pillar, independent civil society, community organizations, and traditional authorities were highly constrained or suppressed. In the wake of decolonization, central governments had suppressed the third pillar, local government, or starved it of fiscal authority and resources. Since none of these three pillars were providing much opportunity for the young woman or man, s/he had to join the central government if s/he wanted to contribute her community. But the central institutions failed the rural sector miserably.

Well structured institutions can tackle all the components of rural development, from health and education to infrastructure, agricultural services, social protection, resource management, and more. Not only does the institutional environment determine who can contribute to development and how successful it will be, it also is the most important determinant of the distribution of the benefits. More specifically, where institutions are dis-empowering, they can be used by strong individuals and groups to direct the benefits of development to themselves, via elite capture (Binswanger 2008).

No single institution by itself can carry the burden of local and rural development. Instead the new paradigm that has emerged gives equal weight to the private sector, communities and civil society, local government, and the sector institutions such as health, education and agriculture (World Bank 2004b). A broad consensus has been reached that local development (and therefore rural development) has to be viewed as a co-production by all these four groups of actors. They need to take account of their comparative advantage, delegate functions to the other partners in co-production, and reform themselves to be able to function under this new paradigm. How such an integrated approach would be fostered in a particular country should depend on past history, what currently exists and can be built on, the prevailing traditions and cultures, and a diagnosis of the existing capacities and dis-functionalities.

The following changes have taken place since 1980 and have contributed to growth and development

*Private Sector:* Private sector opportunities have improved in general as part of improvements in macro-economic and sector policies. The World Bank's agricultural adjustment programs identified the suppression of the private sector, the underperformance of parastatal enterprises, and the fiscal black holes they created as the root cause of the underperformance of agriculture (Binswanger 2008). While this view was partially correct, it was a too narrow. As discussed before, the withdrawal of the parastatals did not lead to spontaneous and rapid growth of private replacements. Too many other problems existed in the "business environment", including corruption, over-regulation, and poor infrastructure and services. The sluggish entry of the private sector into input supply, marketing, rural finance, and technology development and dissemination in Africa has been particularly harmful to the development of the small farm sector, and how to provide these services remains a major challenge of ARD in SSA. Governments will have to play a role in financing a number of these services, without necessarily returning to the failed approaches of government provision. They will also have to create conditions suitable for public-private partnerships, not only with central government institutions, but also with lower level tiers of government.

*Civil Society Organizations:* In the 1980s a broad range of NGOs started to sharply criticize donor financed projects, policies and structural adjustment programs (Mallaby 2004).The focus on communities came from two additional sources: Sector specialists in water supply and natural resource management had started in the 1980s to involve communities systematically, and found this to enhance project performance significantly (Binswanger-Mkhize et al. forthcoming). The other source was social funds, which quickly discovered the power of communities to assist in project design and implementation. From letting communities participate in the design, finance, and maintenance of micro-projects, Community-Driven Development (CDD) programs have moved on to truly empower them to chose, design, and execute a large range of micro-projects, by transferring both the responsibility and the co-financing resources for these projects to them.

A recent review of the Africa portfolio of CDD projects of the World Bank is Serrano-Berthet et al. (2008). Between 1989 and 2007 the World Bank has lent or granted 3.5 billion US dollars for 102 operations in about 40 countries of SSA. Unlike integrated rural development, these projects have a high rate of satisfactory project completion, even though their sustainability ratings are more problematic. From being enclave projects they have become more integrated into the decentralization architecture of countries and become an important instrument for fostering decentralization along with community empowerment. Such funds have also been very useful in assisting communities to recover in post-conflict and other emergency settings (ibid). How to adapt them to such settings is discussed in Cliffe et al. (2003).

While NGOs have become a player in ARD all over Africa their capacity as service providers in Africa has been more limited than in South Asia. In the low population density countries they tend to concentrate around major cities and find it hard to operate in remote rural areas. Using NGOs as implementers and intermediaries in CDD programs proved to be costly and has increasingly been abandoned in favor of direct empowerment of communities with knowledge and resources. NGOs of course remain important facilitators, sources of knowledge, innovators, and advocates for change in ARD-relevant sectors.

For agricultural development, a particularly important development is the formation and progressive development of independent farmers' organizations, and micro-finance institutions (World Bank, 1994). A recent review compared the development of producer associations in Mozambique, Nigeria and Zambia to that in Brazil and Thailand. The review found that "Effective producer associations thrive in a democratic environment that provides a favorable climate for civil society organizations in general. A really active role in defending smallholder rights, including those to land and favorable contracts, has emerged in Brazil and Thailand, but in Africa it is still poorly developed. Although a significant start has been made, few African associations have been able to develop themselves and their commercial linkages sufficiently to take on a major role in service delivery. And many continue to be heavily dependent on donor support. While in the African case study countries farmers' organizations have become significant stakeholders in discussions of agricultural policies, they have not yet been able to generate the strong political will in favor of agriculture which has propelled development of the Cerrado and of North East Thailand" (Binswanger-Mkhize 2007).

*Local government:* During the late 1980s and 1990s, democratization in Latin America and Africa, and the inability of central states to deliver services in widely heterogeneous environments, led to decentralization initiatives in many countries. Unsuccessful decentralization programs are almost always characterized by inadequate allocation of fiscal resources and responsibilities to the local level (Manor 1999; Shah 1994). Local governments can of course become an instrument for elite capture and corruption. To prevent that, they must be democratic institutions, but that in itself is not enough. Without strong communities and civil society, and a strong private sector, local governments will not be subject to the scrutiny and the bargaining processes that are needed to make local development inclusive and efficient.

In the early 1990s, the World Bank first discovered the power of local governments in its CDD programs in Mexico (Binswanger-Mkhize et al. forthcoming), and later in North East Brazil. The innovation spread to the rest of the world. Social funds started to build the capacity of local governments, and entrust them with coordination and some implementation functions. A research program on Decentralization, Fiscal Systems and Rural Development in the mid 1990s (McLean et al. 1998; Piriou-Sall 2007) analyzed the level of decentralization of rural service delivery in 19 countries (or provinces thereof) across the World. Four African countries had the lowest decentralization scores, while Jianxi province in China had the highest one. Latin American countries scored in the upper half, while Karnataka state of India ranked ninth and Punjab, Pakistan 13th. The recent Governance Report of the Economic Commission for Africa (2005) shows that not much progress has been made - in the past decade and a half: Decentralization, along with corruption, still receive some of the lowest scores of a whole series of governance indicators studied in 28 countries of Africa.

In most OECD countries and in the high performing China, local governments perform functions in education, health, social protection, environment, agriculture, land, local and community infrastructure, and promotion of private sector development. They are a multi-sector coordination tool, even though their coordination capacity is always imperfect. There are powerful reasons for using the lowest level of local government for coordination and execution of rural development. At the local level people have direct knowledge of the local conditions. Transparency is relatively easy to achieve, since people can often verify the result of expenditures with their own eyes. Empowered and properly resourced local governments can mobilize latent capacities in communities and at the local level. And finally, local governments exist in remote areas where neither NGOs nor the organized private sector usually operate.

*Sector institutions:* Because of their shortcomings in rural development, there has been a growing realization that the sector institutions should delegate implementation to the private sector, to communities, civil society organization, and to local governments, using the principles of subsidiarity[5] and comparative advantage. They should formulate policies, set standards, and enhance and control quality (World Bank 2004a). Far from withdrawing from ARD, such a change would strengthen the capacity of the overall system to provide the public and quasi-public goods needed by small farmers.

The sector institutions specifically associated with agriculture and natural resources have often performed particularly badly. Agricultural credit institutions not only achieved little for small farmers, they also were fiscal black holes benefiting primarily the better off farmers. Ministries of Lands have lacked an effective constituency to ensure proper budgets for them, are often highly centralized, and corrupt. Ministries of Agriculture are usually weak and politicized, and poor providers of small farmer services. They have great trouble in performing important public good functions, such as collecting the necessary data, monitoring sector developments, analyzing sector policy issues, and designing and implementing appropriate agricultural policy regimes and programs. Efforts to reform individual sectors one by one have had little success. It is now well understood that transformation and de-concentration of the sector institutions is better done via cross-sector governance and public sector reforms.

*Central government:* The central government still has the ultimate design, oversight, and coordination role of national development programs, including those for rural development. It also usually finances much of education, health, and ARD services. The central government has a particularly important role to play in bringing about the changes needed for successful co-production among the four institutional pillars discussed above, including public-private partnerships. It has to drive forward the process of community empowerment and decentralization of functions, resources and accountability mechanisms to local governments and to the end users, and to ensure that the sector institutions transform themselves. It has to ensure that the business climate for the private sector improves, and that communities and civil society are free to take on their co-production functions.

Today the young lady about whom we spoke at the beginning of the section can operate much more freely in the private sector in a steadily improving business environment. In most countries and commodities she can join a producer association. She can also help her community by engaging in a wide variety of community-driven initiatives for which funding is becoming available more systematically. She can work for one of many NGOs and either use her technical skills in NGO-facilitated development programs or her advocacy skills in advocacy NGOs. In countries such as Senegal or Uganda a number of former functions of ministries of agriculture are either being privatized, or performed by producer associations, often partially financed by the state, and the young lady may operate in one of these services. Finally, most countries have pursued decentralization initiatives, and the young lady may work for her locality either as a staff member of a local government, or as an elected counselor. Unfortunately, however, progress in decentralization has been slow in most countries other than Uganda, South Africa, Burkina Faso and a few more. Fiscal decentralization has been lagging badly, leaving most local governments with little resources to execute their mandated functions, let alone taking a leadership role in local development.

Capacity development of agricultural and rural institutions would flourish best in the context of a broader, national capacity development strategy and program. It cannot be done as a top down provision of capacity development services. Instead it involves learning by doing, and mandatory training, in particular in diagnosis and planning, financial management and reporting, procurement, and monitoring and evaluation.

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[5] The principle of subsidiarity states that functions should be allocated to the lowest level capable of effectively performing them while at the same time minimizing adverse spillover effects to neighboring units at the same or higher levels

Other training should be provided largely on a demand-driven basis. Capacity development must build on the considerable latent capacities that are found in rural areas all over the World. To do so, rules and regulations for program execution must become much more participatory and empowering, and eliminate complex features that destroy latent capacity or hinder its mobilization. (Binswanger et al. 2009, chapter 5). Finally, the broader sector institutions involved in ARD need to become much more accountable to their clients.

## RISING FOOD PRICES: SHORT RUN CHALLENGES AND LONG RUN OPPORTUNITIES

OECD and FAO have produced an exhaustive analysis of the recent food price spike and the associated consequences (OECD-FAO 2008). The key facts are as follows: After peaking during the food and energy crisis of the early 1970s, real aggregate food prices, deflated by manufactured import prices from the developed world, declined by 1987 to less than half their peak value. They then stayed flat for nearly 20 years. Between 2005 and early 2008, real aggregate food have risen by more than sixty percent, because of increasing demand from population and income growth, urbanization, declining stocks, and bio-fuel subsidies. The price spikes were aggravated by weather and petroleum price shocks. Prices of individual commodity groups rose much more sharply, with nominal price indices for dairy, oils and fats and cereals spiking at between 150 percent to 200 percent higher than in the 1998-2000 period. Sugar and meat prices rose by roughly 50 percent. The spike was shor lived, and by July 2009 real food prices have leveled out at real prices that are somewhat higher than in the early years of this century.

It should be noted that the spike in aggregate food prices even at their peak did not bring them back to their real levels of the 1960s and early 1970s. The price rises were also a small fraction of the rise in energy prices which started much earlier. Along with the spike, fertilizer prices also exploded. But in October 2008, prices of ammonia and nitrogen fertilizers collapsed, in the case of urea, almost to its level in January 2007. By the end of October 2008, the prices of phosphate fertilizers remained very high, however. These spikes in input prices undermined profitability of agriculture during the food price spike, especially where input use was high.

The recent drop of output and input prices are associated with the global economic crisis which deepened sharply since October of 2008. It is not yet clear how long the economic crisis will last. Energy prices have already fallen to less than half their peak levels. Food and fertilizer prices could fall further in the coming year as well. How low they will go depends primarily on what happens to growth in emerging countries, including Africa. As discussed above, the IMF projects higher growth to resume in all emerging regions in 2009 and 2010. It also projects a resumption of per capita income growth even in Africa. Food prices may therefore not drop to the level of the turn of the century. Because of biofuel production, the oil price will also continue to influence cereal and oilseed prices, and probably put a floor under them.

While the short run outlook for prices is very uncertain, the medium and long term outlook is more relevant for the topics pursued in this paper. Once the world recovers from the current economic crisis, the demand forces that have driven the rising food prices will reassert themselves. OECD-FAO, the International Food Policy Research Institute (IFPRI), and other analysts, all agree that in the medium to long term the prices will settle at a significantly higher level than those around the year 2000, and that the underlying trends in demand will lead to gradually increasing prices for decades to come. The period of globally falling real prices of food, therefore, appears to have come to an end.

### The Short Run Challenges

The food price spike seriously affected the balance of trade of net food importing countries. Many of these are in Africa, and especially so in Eastern, Southern and Central Africa. Most of these hard hit countries were already reeling under the impact of the higher petroleum import costs. Almost half of 77 countries surveyed by FAO in early 2008 had reduced import taxes on food. However, for food importing countries the price reduction achievable were sharply limited, and could not exceed the tax collected prior to their reduction. Therefore 55 percent of countries resorted to food subsidies or price controls. Only about 25 percent of countries have been able to dip into existing food reserves. An even lower percentage of countries, only about 17 percent, responded via measures to increase the food supply. Most net food exporters surveyed by FAO resorted to export bans or increases in export taxes. As a consequence of these policy measures, the pass-through of higher rice prices to domestic prices ranged from 6, 9 and 11 percent of the international price rise respectively in the Philippines, India and Vietnam, all of them net food exporters. The price rises were 43, 53, and 64 percent respectively in Bangladesh, Indonesia and China who import some and export other foods.

A recent debate in the Economist between Homi Kharras and Joachim von Braun (Economist, 2008), discussed the question whether the high food prices, on balance, would be good for the World's poor or not. The upshot of the debate is that (1) higher food prices are needed to bring forth the increased supplies of food that are needed, although the policy interventions just discussed slow down the supply response; (2) many poor producers, who are net sellers of food, will gain from the higher food prices, as the example of Vietnam discussed below suggests: (3) the price explosion will be particularly bad for the urban poor and for farmers who are net buyers of food, as most poor farmers in SSA are; and (4) a more gradual and modest rise in food prices would have created less of a negative impact on the poor and allowed wages to adjust better to the higher prices, and also would have enabled farmers to respond to the rising prices and thereby either reduce their losses or increase their gains.

Ivanic and Martin (2008) took high quality household data from 10 countries to simulate the short run impact of the rise in commodity prices from 2005 to 2007 on poverty incidence and depth. Longer run impacts that arise from rural linkage effects (via forward, backward and consumer demand linkages) that come about as a consequence of higher farm profits associated with higher output prices are not included in the analysis. Their analysis assumes a full pass through of higher international prices to the domestic economy and no countervailing food subsidies. Nevertheless, their analysis sharply illustrates the disparities in short term poverty impacts of identical food price rises around the globe: For urban populations in Nicaragua, who spend a large share of their income on the foods, the impact is a more than 10 percent rise in the poverty rate. Rural populations of Zambia, who are mostly net buyers of maize, are the second worst affected and see their poverty rate increase by around 7 percent. In Malawi and Madagascar, poverty rates increase between 3 and 4 percent. On the other hand, the rural poverty rate in Vietnam declines by 3.1 percent, because the asset distribution in rural areas is very equal and most of them are net sellers of rice, maize and poultry. The changes in depth of poverty paint a similar picture to the changes in the poverty rates.

These back of the envelope calculations ignore all the positive impacts that higher food prices could have in the medium to long term via forward, backward and consumer demand or via wage improvements. They therefore measure the poverty impact of what is most likely to be a transitory spike in food prices. Nevertheless, these estimates are a good indicator of what policy makers were up to if they want to mitigate the adverse poverty effect of the food price spike in the short run. Clearly this is a monumental task: It is not only the additional poor people who need help most of those among the 2.1 billion who were poor before the food price spike. Small increases in safety net programs that rarely have significant coverage in the first place were not up to the task at all. No wonder therefore that policy makers have preferred the aggregate measures such as reducing taxation of food, general food subsidies or price controls, releases from stocks and export controls. Of course some of these measures have poor fiscal sustainability and prevent necessary adjustments in consumption and production of food. But if these measures were indeed used only to mitigate the short run impacts of a spike and then quickly phased out, they may well have been justified.

In the longer run, modestly higher and gradually rising food prices are good for rural populations, because they lead to greater investments, outputs, profits and rural wage rates. Farm-nonfarm linkages will spur an expansion in the rural non-farm sector and enhance these positive effects. For economies dominated by agricultural sectors, there may also be important positive linkage effects on urban economies, as well as higher unskilled urban wages. The higher food prices projected for the future are therefore likely to provide important long run benefits for many African economies, and especially for rural populations.

### The Market Opportunities

Even before the recent price spike, a number of analysts, including FAO, have evaluated the market opportunities they would bring to African farmers: The bright international medium to long term market outlook for food does not necessarily mean that the best opportunities are in global markets (Poulton et al. 2006; World Bank forthcoming). Since Africa has become a major food importer, African producers compete in these markets at the import parity price rather than the lower export parity price. In addition, quality standards are not as high and phyto-sanitary barriers lower than in international markets. The combined value of domestic and regional markets for food staples within SSA is considerably in excess of its total international agricultural exports (Diao et al. 2006). Africa's demand for food staples is projected to about double by 2020. Moreover, an increasing share of output will become commercialized as the continent becomes more urbanized. Bottlenecks in road and export infrastructure in SSA are likely to be removed only gradually, reinforcing the opportunities in domestic and regional markets. Nevertheless, as a recent analysis of IFPRI of prospects in East and Central Africa shows "among agricultural sub-sectors for which there is large and growing domestic and regional demand, staples loom large as a group. Production and sale of these "poor man" crops can be pathways out of poverty for millions of citizens of ECA." (Omamo et al. 2006).

The fact that domestic and sub-regional markets for food crops present the best opportunities does not mean that there are no opportunities in international markets. Unfortunately SSA has yet to record any significant global export success in low value commodities (e.g. cereals, cassava, soybeans) that can be grown in a wide range of locations, including by mechanization (Poulten et al. 2006). With appropriate policies and investments, including in transport infrastructure and technology, the past need not to repeat itself.

This discussion does of course not imply that Africa should not seize opportunities in export commodities in general, or in horticultural products, fair trade and organic agriculture. While not as large as the opportunities in domestic and regional food markets, they are significant and have considerable direct and indirect employment impacts. They are being seized by an increasing number of countries in addition to Kenya. There are numerous examples of benefits arising for African producers from fair trade initiatives, as for example in coffee. And African producers use no or limited inputs that should give them many niche opportunities in organic agricultural products.

Sub-regional trade could be a relatively efficient way of smoothing out the impacts of droughts on production and prices at country and sub-regional levels. There are many physical and institutional impediments to cross-border trade within Africa, including differences in food safety requirements, rules of origin and quality and product standards. More importantly, trade in food staples was for long discouraged by national food policies that placed a high priority on self sufficiency, and vestiges of these policies still prevail in many countries. One of the biggest impediments to large-scale private investment in cross-border trading capability – particularly in Southern and Eastern Africa – is the unpredictable behavior of governments in imposing export bans whenever they fear food shortages in their own markets.

*That domestic and regional markets are the most promising area for medium to long term agricultural growth means that small farmers, despite the supermarket revolution and rising international quality standards, will be well placed to seize them. At the same time these conclusions mean that countries and their development partners need to focus more on improving access and trade in regional and sub-regional food markets. Reducing the barriers to regional food trade appears to be a major imperative.*

## CLIMATE CHANGE

Africa has experienced enormous climate changes since it gave rise to mankind about 150,000 years ago. Ever since the onset of agriculture about 8000 years ago, climates have changed periodically. The most important evidence to this is found in the records of two periods of pastoralism that have covered much of the Sahara desert, only to retreat again since about 4500 years ago (Reader 1998, p. 171ff). The adaptive capacity of African agriculture to these enormous climate changes in the past is well documented. It also has suffered repeated long term droughts with devastating impacts on population size and welfare, such as the decade long drought that afflicted West and Central Africa between 1774-1785, and that, inter alia, contributed to the peak in the transatlantic slave trade (ibid, p. 429 ff).

### What does the IPCC say about Future Climate Change in Africa?

Except for a few diehards, there is now agreement that global warming is caused by human activity. The current data and projections from modeling efforts of global climate change have been summarized in the latest Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2007). The IPCC coordinates the numerous modeling efforts across the World. It emphasizes that projections are associated with uncertainties, which varies widely across the different types of impacts of climate change. It therefore assigns confidence levels on a scale of 1 to 10 to those where quantitative expert judgment is used, and statistical likelihood for those where expert judgment is combined with statistical analysis, ranging from extremely likely (> 95 percent) to very unlikely (< 10 percent). In the following, selected findings from the IPCC report are presented.

*Observed temperatures* have increased across wide areas of the World. They are higher in the higher northern latitudes than elsewhere. Land regions have warmed faster than the oceans, but oceans have been taking up over 80 percent of the heat added to the climate system. Consistent with these trends, arctic sea ice has shrunk by 2.7 percent per decade, while mountain glaciers and snow cover have declined in both hemispheres. Between 1900 and 2005, precipitation increased significantly in the eastern parts of North and South America, northern Europe, and Northern and Central Asia, whereas they have declined in the Sahel, the Mediterranean, southern Africa and parts of South Asia. Areas affected by drought across the world are *likely to have increased.* It is *very likely* that hot days and hot nights have become more frequent; it is *likely* that heat waves have become more frequent, and that frequency of heavy precipitation events has increased. There is *medium* confidence that agricultural and forestry management at higher latitudes in the Northern Hemisphere has changed, including earlier spring plantings of crops and disturbances of forests due to fires and pests. There are also things *that have not changed*, such as Antarctic temperatures and sea ice. There is no discernible trend in the meridional overturning circulation (MOC) of the oceans, and in small scale phenomena such as tornados, hail, lightning or dust storms. There is also no clear trend in tropical cyclones.

The modeling efforts suggest that, with greenhouse gas emissions at current or higher levels than in the past, it is *very likely that temperature changes during the 21st century would be faster* than in the 20th century, ranging from between 1.4 to 5.8 degrees Celsius depending on the scenario. The projected warming will follow similar patterns than the observed warming in the past: it will be higher over land than the oceans, highest in the most northern latitudes and least over the southern oceans near Antarctica and in the Northern Atlantic. Night temperatures *are likely* to increase more than day temperatures.

Increase of *precipitation* are *very likely* in the high latitudes, while decreases are *likely* in subtropical areas. While the Greenland ice sheet is projected to contribute to current sea level rises, the Antarctic ice sheet will remain too cold for widespread surface ice melting. While it is *very likely* that the meridional overturning circulation (MOC) in the Atlantic Ocean will slow down, it is *very unlikely* that it will undergo a large, abrupt transition. There is also a growing view that frequency and amplitude of extreme weather events may be increasing. It is *very likely* that hot extremes, heat waves, and heavy precipitation will increase.

*Specifically for Africa*, climate change and its impacts are estimated to be considerably more adverse than predictions for the developed World, but less alarming then for example for India and for Mexico. *Observed* precipitation changes have been complex: In West Africa a decline in precipitation has been observed since the end of the 1960s, ranging from 20 to 40 percent between the period of 1931-1960 and the period since then. A 10 percent increase in annual rainfall has been observed along the Guinean Coast, however. Eastern Africa has seen increasing rainfall over the northern sector and decreasing rainfall over the southern sector. In other regions, no long term trend has been noted. In different part of southern Africa a significant increase in heavy rainfall events has also been observed. Lake Victoria, Tanganyika and Malawi have risen by 1.7, 2.1, and 1.8 meters respectively through a combination of higher rainfall and/or higher runoff.

Very few regional to sub-regional climate change scenarios have been constructed in Africa. The global models imply that the highest *increases in temperature* are expected in the Mediterranean Region of North Africa and the extreme south of Africa. The role of land use and vegetation cover emerges as a key determinant of future temperature changes, with higher vegetation densities in the tropics, including in the tropics of Africa suggested to result in a year round cooling of 0.8 degrees Celsius. Sea level rises will significantly affect Africa's delta regions such as the Niger Delta.

*Precipitation projections* are generally less consistent across climate model than temperature changes. Nevertheless it is *very likely* that precipitation will decrease along the Mediterranean Coast and in the Northern Sahara, but is *likely to increase* in tropical and Eastern Africa. Austral winter rain is very probable to decrease. For the Western Sahel there are still discrepancies between the models, some projecting a significant drying and other simulating a progressive wetting with an expansion of vegetation into the Sahara. Discrepancies in model predictions are also large for Southern Africa (except the southernmost Mediterranean tip). Predictions of runoff vary widely, because small variations in extreme weather events can have a major impact on runoff. Nevertheless, water stress is expected to increase in Northern and

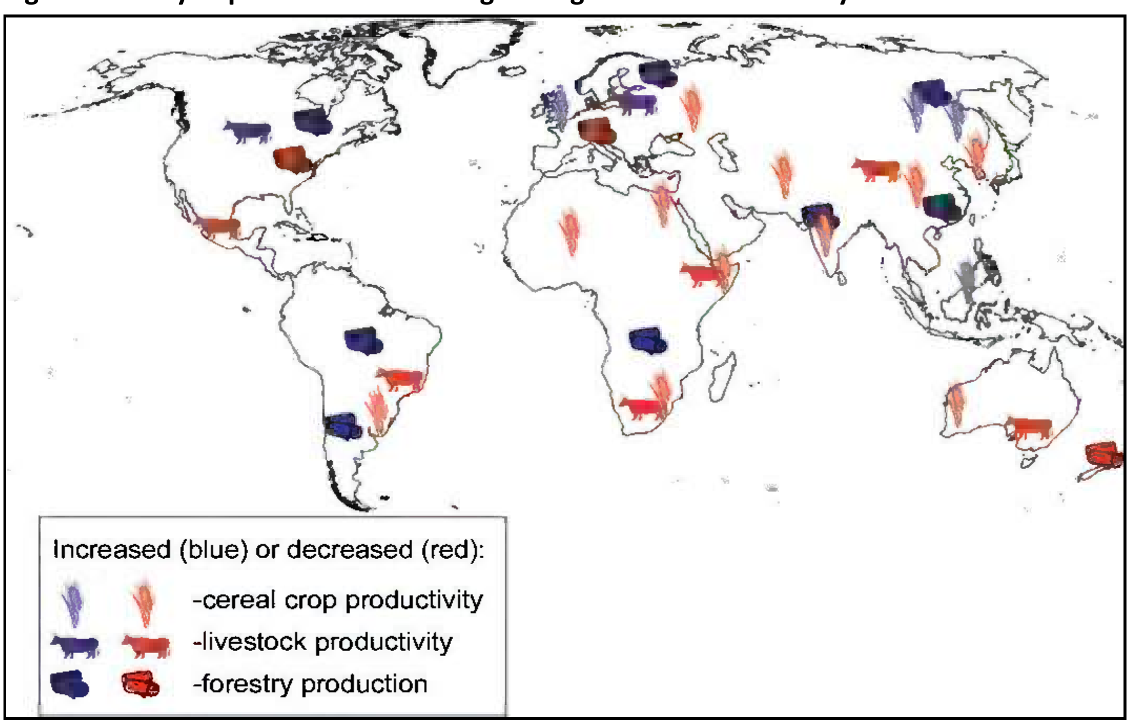
Southern Africa, while more people in eastern and western Africa will be likely to experience a reduction, rather than an increase in water stress. It is clear, therefore, that the most serious impacts of climate change are expected to affect the Mediterranean climate areas in the North and extreme South of Africa. By 2020, between 75 to 250 million people are projected to be exposed to increase water stress. On balance, by 2080 an increase of 5 to 8 percent in arid and semi arid and in Africa is projected under a range of climate models.

### How much Impact will Climate Change have on Agriculture Countries?

The IPCC (2007) summary report states that approximately 20 to 30 percent of plant and animal species assessed so far are *likely* to be at increased risk of extinction if global average temperature increases exceed 1.5 to 2.5 degrees Celsius. Crop productivity is expected to increase slightly at mid to high latitudes for temperature increase of up to 1 to 3 degrees, but would be adversely affected if temperature rises were higher. In seasonally dry and tropical regions crop productivity is expected to decrease for even small local temperature increases of 1 to 2 degrees (*medium confidence)*. As a consequence, global food production *is expected to increase* with temperature increases in the range of 1 to 3 degrees, but to decrease above this range. (IPCC 2007, chapter 5). Fisher et al. (2002, quoted in IPCC 2007, chapter 7) "quantify the impact of climate change on global agricultural GDP by 2080 as between -1.45% and + 2.6%"

Without climate change the report assumes that socioeconomic development would reduce the number of hungry people from 820 million today to the 100-230 million range. Scenarios with climate change project increases in the number of hungry people between 40 and 170 million relative to that base. Increases in extreme weather events may reduce food production below what is predicted for mean temperature rises. Potential adaptation to climate change would significantly reduce negative impacts. However, groups whose adaptive capacity is constrained would experience the negative effects on yields of low latitude crops, combined with high vulnerability to extreme events. Globally commercial forestry production rises modestly in response to climate change, with large regional variations. "Fisher et al. concluded that there will be major gains in potential agricultural land by 2080, particularly in North America (20-50% and in the Russian Federation (40-70%, but losses up to 9% in sub-Saharan Africa." (IPCC 2007, Chapter 5). It should be noted, however, that currently Africa is only using about 32 percent of its potential arable land. A summary of global agricultural and forestry impacts is given in Figure 5.

**Figure 5: Likely impact of climate change on agriculture and forestry across the World**




Source: IPCC (2007)

The implications of this summary of the IPCC are that climate change is likely to have severe impacts on Africa, probably more negative than positive. The report, however, warns that "impacts research is hampered by the paucity of regional models for Africa, and by the uncertainties surrounding regional projections of climate change of global models, particularly precipitation". In addition the report provides a long list of additional knowledge gaps, including lack of knowledge of $CO_2$ responses for crops other than cereals; poor understanding of the combined impact of elevated $CO_2$ and climate change on pests, weeds, and diseases; great uncertainty about the impact of changed frequency of extreme weather events, and poor understanding of adaptation capacity of food and forestry systems. For the remainder of this report this means that, for most specific agricultural production regions, it is still extremely difficult, or even impossible, to predict the likely impacts of climate change on agriculture and bio-diversity. This severely limits the scope of planning for adaptation to climate change at this time.

Despite these uncertainties, efforts to predict impacts of climate change on agriculture at regional and local levels have proceeded, the most comprehensive of which is Cline (2007). The book contains an excellent review of the prior literature. Contrary to the studies summarized in the IPCC report, the author finds that, taking into account an average 15 percent yield increase from carbon fertilization, climate change by the end of this century would have a modest negative aggregate effect on global food production. But similar to earlier findings, negative effects would be concentrated in the developing World, including Latin America, Africa and India. Without carbon fertilization the effects would be significantly more adverse.

The methodological features of the study by Cline (2007) are as follows: It is geographically very detailed and obtains impact estimates for more than 100 countries, regions, and regional subzones of the largest countries. It directly links six Global Climate Models to highly detailed predictions of the climate for a grid across the globe that has a total of 2800 land-based cells, and then averages these across the six models. The cell averages are then aggregated to the country level, or for large countries, to regional levels. The model therefore ignores all variability and uncertainty in outcomes that are significant across models, especially at regional and country levels. The averaging across climate models is justified, because emphasizing uncertainties might lead to policy paralysis. The book provides agricultural impact estimates with and without carbon fertilization; and it separately estimates climate impacts for irrigated and non-irrigated agriculture.

The baselines scenario used by Cline (2007) is the A2 Scenario of the IPCC. It assumes an extremely high population growth of all the scenarios to about 15 million people by the end of this century, very much higher than UN population projections. It combines this with the lowest per capita income growth of all scenarios. Despite low income growth the typical developing country person will still have an income almost as high as today's developed country person. In addition, it assumes little technical change to reduce carbon emission and no abatement policies. Clearly this scenario is among the least favorable ones considered by the IPCC.

While for other regions it uses both "Ricardian" approaches as well as crop models to assess the likely impact of climate change on agricultural output, for Africa only the "Ricardian" Approach is used. "The classical economist David Ricardo developed the theory that the value of land depends on the difference between its fertility and that of the least fertile land just brought into cultivation at the margin. The seminal Ricardian agricultural impact model (Mendelsohn et al. 1994, as quoted in Cline 2007) argued that statistical regressions relating land values to climate differences could capture the impact of climate on agricultural productivity and thus be used to calculate prospective effects of global warming" (Cline 2007, pp. 4-5). Model estimates from many African countries come from World Bank data reported in Kurukulasuriya et al. (2006). For Africa, the model fits regressions of net revenue per hectare of land on average precipitation and rainfall in several seasons, and on their respective squared terms. The regressions are run separately for dryland and irrigated areas.

Using this approach assumes that net revenues observed in an area with different climate B would be the net revenues that farmers in a given climate A could obtain if their climate changed from A to B. In this approach it is assumed that farmers have a lot of time to adapt, and therefore that adaptation is costless. A weakness of the approach is that this ignores specific constraints or opportunities in area A that could either hinder or facilitate the adaptation process, relative to adaptation to what is currently occurring in area B. The statistical assumption behind this approach is that both rainfall and temperature are totally uncorrelated with any other determinant of output that affects net revenues per hectare over space. Barring very long time series data, the validity of the assumption is not testable.

How tenuous these assumptions are is illustrated by the model predictions that result for irrigated agriculture when Egypt is included in the regressions for Africa: "(…) for variant A of the irrigated agriculture model (including Egypt), the median change [in value of output] is 24.4 percent. However, when variant B of the irrigated agriculture model is applied (excluding Egypt in the parameter estimation), negative results also dominate irrigated agriculture, with the median change at -11.1 percent" (Cline 2007, pp. 53-56). It appears that the results from the regressions including Egypt contain serious left out variable biases: Egypt is known to use much higher technology levels than sub-Saharan African agriculture. By not including any variables that could explain these higher productivities, the productivity effect is included in the coefficients of temperature and rainfall, which as a result are seriously biased. That this is indeed a major issue is illustrated by the fact that the IPCC stresses the high risks of global warming to Egyptian irrigated agriculture, because Egyptian irrigation water availability will be at risk and because temperatures are already extremely high, and further rises will likely lead to yield losses (IPCC 2007).

Cline (2007) comes to the following additional conclusions: "There is a predominant pattern of large negative changes [in the value of output] from business as usual warming (excluding carbon fertilization) in dryland African agriculture. The median change is -31 percent. (…) There is a high frequency of severely adverse effects for dryland agriculture, as five of the 28 countries or regions have complete shutdown. Another six have reductions in agricultural capacity by about half or more. However, four countries have only modest declines averaging about 3 percent, and two countries or regions have modest increases. (…) A second pattern is that several countries show major gains for irrigated agriculture if the model heavily influenced by Egypt and its Nile water is used (variant A), but the pattern shifts to dominant losses even in irrigated agriculture if the function omitting the Egypt observations is applied (variant B)."

The study further continues "For each country or region, the weighted average impact of climate change is calculated by weighting the dryland and irrigated estimates by their respective value shares in the base period. This estimate excludes the carbon fertilization effect. When this estimate is aggregated across all African countries and regions by weighting by base period agricultural output, the result is that African agricultural capacity would decline by an estimated 18.6 percent by the 2080s, before taking account of carbon fertilization. Excluding Egypt, the decline would be about 30 percent. A com parable set of estimates including carbon fertilization is obtained by applying a uniform 15 percent enhancement of yields from this effect by the 2080s, as discussed above. The result is a still substantial aggregate decline of 6.3 percent in the aggregate and about 19 percent excluding Egypt" (Cline 2007, pp. 53-56).

It is clear from the above quote, that despite the use of a single climate scenario, and despite the averaging of the results of this scenario across six different climate models, the final results remain highly uncertain. While left out variable bias appears to be quite clear for irrigated agriculture, there is no reason to expect that it does not affect the dryland regressions and predictions. The inclusion or exclusion of the carbon fertilization effects turns estimates from relatively benign to enormous.

The question therefore becomes: What can such country-specific estimates of agricultural impacts be used for? Clearly the country-specific climate estimates cannot be used for planning specific adaptations to climate change in particular countries or sub-regions. Apart from the uncertainties and weaknesses of climate modeling in Africa stressed by the IPCC reports and discussed above, and apart from the question of left out variable bias, the resulting country-specific climate estimates suppress any variations among climate models. But the average climate effect is not the one that is going to be realized. Rather only one of the models can be close to what is actually going to happen in a given country, and maybe none of them will. We are therefore left with estimates which can at best be used for advocacy, especially at the continental scale.

It is also important to put the various estimates of the impact of climate change into perspective relative to economic growth and anticipated or possible technical change in agriculture. First of all, the A2 "business as usual" scenario of the IPCC assumes that per capita income in Africa in the period 2080-2100 will be about six to eight times that of today. At such income levels, Africa could afford to import food from other, less severely affected regions. Second, even under the worst scenario of a 30 percent lower output that without carbon fertilization, a rate of factor productivity growth of about one-third of a percent per year would be sufficient to offset the loss. *Except for Africa, most regions of the World have had total factor productivity growth in excess of 1 percent per year for decades. There is little reason to believe that Africa could not achieve similar rates, which would be more than enough to offset the impact of climate change under the worst case scenario without carbon fertilization.*

### Key Issues raised by Climate Change

The basic questions raised by climate change now are, can the process be slowed, stopped or even reversed, and at what cost. This is the issue of mitigation. The second issue is adaptation i.e. how will the world adjust to the outcome. For African farmers the general challenges are obvious: They increase agronomic complexity and increase risks of shocks at the farm and community levels and imply additional changes in crops, cropping patterns, timing, agronomic practices, and seed needs. But the specifics of these changes cannot be predicted. Therefore, in terms of adaptation in Africa, what is required is strengthening of capacities of African agriculture and food systems to adapt to climate change, via improved technology generation and adoption systems, more and better irrigation and drainage, better markets, greater ability to import foods in bad years or on a year round basis, greater preparedness for extreme weather events, and better safety nets. However, all these improvements are also most urgently needed even if there were no climate change. Climate change, therefore, does not generate a separate agenda for agricultural and rural development, only reinforcements of existing agendas. Adaptation to climate change needs to be mainstreamed into this general agenda.

This point is not new: Yohe et al. (2007) in a section headed “Mainstreaming Adaptation into Development Planning”, conclude “(...) the tendency has been to treat adaptation to climate change as a stand-alone activity, but it should be integrated into development projects, plans, policies, and strategies.”(ibid p.2) Howden et al. (2007) make a similar argument “We argue that achieving increased adaptation action will necessitate integration of climate change-related issues with other risk factors, such as climate variability and market risk, and with other policy domains, such as sustainable development.”

We should also note that African farmers will be better able to do so if agriculture is highly profitable and they have the required savings to invest into these adaptations. This reinforces the profitability agenda that is heavily stressed in this paper. In addition, there may be areas which will go out of agriculture, or which may switch from agro-pastoral systems to extensive pastoralism, and require more outmigration. Therefore, as stressed elsewhere in the paper, regional integration will become more important to provide destinations for migrants, especially from countries such as Niger or the Sudan, and allow for free trade in food.

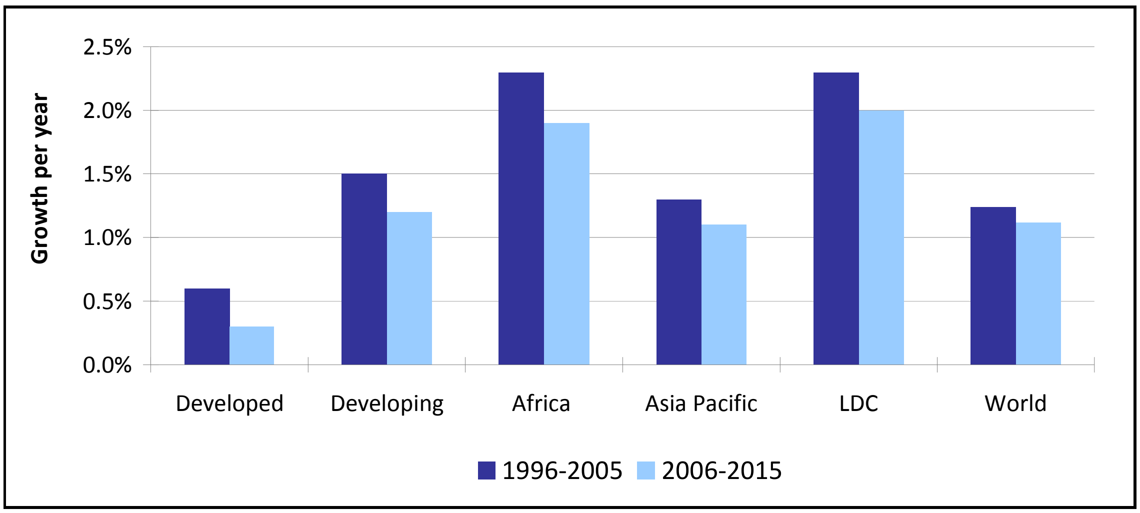
The debate about mitigation versus adaptation has recently been joined by Björn Lomborg in his book Cool It: The Skeptical Environmentalist’s Guide to Global Warming (2007). Lomborg’s case is that we should do a serious cost-benefit analysis comparing the benefits of spending a lot of money on minimal reductions on $CO_2$, or the same or less money on pressing current issues. For our purposes, his book is useful in highlighting that this is a real trade off and no-where is this more true than in tropical and sub-tropical agriculture, i.e. African agriculture. SSA is the continent contributing the least to global warming. It has the most urgent economic and social problems that press on the current generation, and that will be less for future, more wealthy generations. Except for land use changes discussed below, the case for putting less emphasis on mitigation in SSA, and more on dealing with the pressing current needs, and with capacity building for future adaptation is stronger here than anywhere else.

African agriculture, on the other hand, can take advantage of opportunities that climate change may present. The question is how it should do this. “Climate mitigation through carbon offsets and carbon trading can increase income in rural areas in developing countries, directly improving livelihoods while enhancing adaptive capacity”. (Yohe et al. 2007, p.1) “Land use change (18.2%) and agriculture (13.5%) together create nearly one-third of greenhouse gas emissions. (…) Achieving significant carbon mitigation in developing countries will require tapping carbon offsets from agriculture and land use change. While not as large as potential savings from reducing the consumption of fossil fuels, the total potential saving (…) is still substantial and is achievable at a competitive cost. With as much as 13 gigatons of carbon dioxide per year at prices of US$10-20 per ton, this represents potential financial flows of US$130-260 billion annually, comparable to ODA of US$100billion, and foreign direct investment in developing countries of US$150 billion.” (ibid p.3). It is clear that to take advantage of these opportunities will require the building of appropriate policies and institutions at national, sub-regional and regional levels.

## POPULATION GROWTH

Following several centuries of population stagnation attributable to the slave trade and colonization, the population of SSA increased from 100 million in 1900 to 770 million in 2005. Despite HIV and AIDS, the population growth rate remains at nearly 2 percent per year. Figure 6 shows that population growth for the World as a whole is slowing but remains at around 1 percent per year. The slowdown is happening in Africa as well, but the decline is from the highest level in the World at 2.3 percent to about 1.9 percent for the decade to 2015. As in other regions, population growth will be much faster in urban regions of Africa than in rural regions. From only one city with a population of more than 1 million in 1960 (Johannesburg) the number has grown to over 40. Despite rapid rural-urban migration, the high population growth rates mean that the absolute number of rural people will continue to grow in SSA, and poverty will remain concentrated in rural areas for a long time.

**Figure 6: World population growth, 1996-2005 and 2006-2015**




Source United Nations (2006)

While HIV and AIDS reduce population growth rates in the highest prevalence countries of East and Southern Africa, the UN population projections do not expect population growth to become negative in a single country (United Nations 2006). Therefore the latest United Nations projections, expect population in SSA to grow to between 1.5 to 2 billion by 2050. Already today, the population density of SSA is 32 persons per km$^2$, higher than in Latin America where it is 28 per km$^2$ (IRD 2007). This is of course much lower than Asia, and Africa and Latin America have the highest reserves of arable land in the World. SSA has an exceptionally high fecundity of five or more children per women, as less than 20 percent use any birth control measures as against more than 60 percent in Latin America and Asia. The region also has an exceptionally high mortality rate, and the average HIV and AIDS prevalence rate leads to a high death rate of prime age adults. As a consequence the region has more than two-thirds of its population under 25 years of age, twice the proportion in Europe. The high dependency rate is a drag on economic growth.

### The Implications of High Population Growth for Economic Growth

Globally, declines in fertility rates seem to be linked to income growth, urbanization, girls' education, and reduced infant and child mortality rates, all of which have been delayed in SSA because of stagnant growth rates. The past failure to grow therefore is one of the main reasons for the failure of the population growth rate to decline as fast as for example in Asia and the Pacific. But the situation is changing: Since per capita growth is now around 4 percent in SSA, the demographic transition will undoubtedly accelerate in the next decades.

But the relationship between population growth and economic growth also works the other way around. A very important reason for poor investment incentives and returns in Africa is that the demographic transition in Africa began later than elsewhere and is slower than in the rest of the World, leading to much higher dependency rates than elsewhere. The current situation results in a high level of age dependency, which reduces saving, reduces investment in human capital, and results in slower growth of the labor force. This creates both fiscal pressures for the government as well as household pressures. The delayed demographic transition in SSA consistently predicts two-thirds of the difference in growth performance with the rest of the developing World (Ndulu et al. 2007). Lower life expectancies are also shown to contribute to the poorer growth performance, and the AIDS epidemic has made this factor much worse, especially in Eastern and Southern Africa. A decline in the population growth rate would reduce dependency rates and lead to a population pyramid with a large adult labor force, compared to a much smaller population of the aged, and a relatively smaller population of children and youth. Dependency rates would decline.

This would set the stage for a population dividend in terms of growth. This is precisely what many Asian economies are currently experiencing. The needed policy elements are improvements in female education, generalization of AIDS, tuberculosis and malaria treatment and prevention, and family planning. Countries and donors are investing more in education and health, but donors have reduced their funding for family planning programs. It would be well to revisit the relative priority of investments in family planning.

But the population dividend in Africa is a long way off: SSA is home to over 200 million young people who are between 12 and 24 years old. The demographic transition to reduce the proportion of young people in the population has barely started, and a decline in absolute numbers will only come in the distant future. The poor quality of primary education severely limits their opportunities: in many countries fewer than half of women aged 15-24 can even read a simple sentence, and their drop-out rates are very high. Young adults are at greatest risk of HIV and AIDS, and the more so, the less they stay in school. In Kenya the probability that a 20 year old may die before age 40 is 36 percent while it would only be 8 percent in the absence of HIV and AIDS. Many young people become combatants and lose future opportunities as a consequence: They number 100,000 in Sudan alone. (World Bank 2006).

As in all regions of the World, unemployment is concentrated among the young. In most countries the share of unemployment of youth is more than 50 percent, and employment is the key concern among them (World Bank 2006). Among women, including the young ones, a low labor force participation rate persists. Schooling for both young men and women has increased, but is yet insufficient to ensure gainful employment of the young generation.

*Development policies must therefore emphasize generating productive employment and improving the domestic investment environment. Since agriculture has a high employment intensity, both directly and via its rural and urban linkage effects, it should receive a very high priority in the countries of the Region.*

### Population Growth and Africa's Land Resources

Of Africa's most valuable resource, the 2007 African Development Report said it best; "Land is a critical natural resource in Africa and the basis of survival for the majority of Africans. (…) If sustainably managed, the African landscape, a rich and dynamic mosaic of resources, holds vast opportunities for the development of human well being." (African Development Bank 2007, p. xvi) Yet, it is frequently argued that this valuable resource is being severely degraded. Land degradations caused by nutrient depletion, soil erosion, salinization, pollution, overgrazing and deforestation are clearly major issues in African agriculture. Many are of the view that low and declining soil fertility is a critical problem in Africa. The InterAcademy Council says: "Depletion of soil fertility is a major biophysical cause of low per capita food production in Africa. (...) Smallholders have removed large quantities of nutrients from their soils without applying sufficient quantities of manure or fertilizers to replenish the soil."(InterAcademy Council 2005, p.47). Global attempts at dealing with the issues of desertification and the related issue of biodiversity loss are dealt with in various international accords including the Conventions on Desertification and Biodiversity. The new Gates / Rockefeller Foundations initiative Alliance for a Green Revolution for Africa (AGRA) has also identified soil health as one of it priority program areas.

Similarly, the World Bank in its News & Broadcast of November 7, 2007 article entitled "Desertification and Land Degradation Threaten Africa's Livelihoods" defines the issues and describes what action it is taking.

"Desertification is a very severe form of land degradation, involving the steady but gradual loss of agricultural productivity and distinct decline of ecological health. The phenomenon matters for Africa's environmental future, more so for the brake it puts on economic activities directly tied to healthy ecosystems. Take the case of farming. Desertification, drought and lately, climate change are all adversely impacting farming, threatening the principal source of livelihood – and exports – for millions of poor people. To tackle the problem of land degradation more forcefully in Sub-Saharan Africa, in 2005 the World Bank and its partners, including the New Partnership for Africa's Development (NEPAD), launched the TerrAfrica initiative tasked with promoting sustainable land management practices by mobilizing coalitions, knowledge, and scale up financing."

It is troubling that most of the evidence for rapid and severe land degradation is however anecdotal, based on local soil surveys and multitudes of plot studies. (Stocking 1996). As far as we can determine, there has never been a comprehensive soil survey for most of Africa and, beyond soil vulnerability maps, there are no current or historical soil degradation maps. Fortunately the Global Environmental Facility has recently funded a global Land Degradation Assessment for Drylands (LADA) that is executed by FAO, UNEP, and a number of collaborating institutions. It is based on worldwide satellite measurement of vegetation covers in 8km x 8km grids with national and local follow up. The local follow up focuses both on hotspots, i.e. the areas with the most land degradation, as well as bright spots, where degradation has been reversed. It appears that globally and in most places vegetation cover has increased over the past 25 years, except in a number of hotspots, such as the former homelands of South Africa (personal communication Freddy Nachtergaele). A full analysis of the results has, however, not yet been published.

Neither higher population nor poverty necessarily leads to land degradation. In the transition from long fallow systems to permanent agriculture soil fertility initially declines and farmers eventually have to introduce new techniques to stem and reverse this decline. This they tend to do during the evolution of the farming system to higher land use intensity, as discussed so well by Boserup (1965) and Ruthenberg (1973). The so called "Boserup Effects" of higher population densities and market access include:

- The intensification of land use
- A shift from hand hoes to plows
- The increasing use of organic and inorganic fertilizer
- The shift to integrated crop-livestock systems
- Investment in land and irrigation facilities
- An increase in the use of agricultural labor
- Higher agricultural production per unit of land

These theories are consistent with a vast number of studies, which have shown that the normal processes of land improvement associated with agricultural intensification are taking place in many countries in SSA. (e.g. Pingali et al. 1987; Tiffen et al. 1994). For example, thirty years ago a World Bank sector report estimated that land losses in Burkina Faso amounted to something like 2 percent of GDP per year. Today the land supports nearly twice the population than in 1980. Kabore and Reij (2004) have documented how this was achieved. The change is visible to the naked eye: On a recent visit by the author of this paper, crops looked greener and healthier than the visitor had ever seen them before, crop livestock integration had happened in many parts, degraded arid lands were being recuperated via traditional and new techniques, and a number of new crop varieties had been introduced, there were more trees on the land. The experience of high population density countries such as China, Japan, the Netherlands or Italy is equally encouraging in terms of sustainable resource use under high population densities and developed markets.

Significant cases of soil degradation, on the other hand, are usually associated with open access regimes, insecurity of tenure, and other policy failure, which imply that the normal investment responses of individuals are impeded (Heath and Binswanger 1996). Clearly, the alarmist view that in many parts of the developing World land is being rapidly and irreversibly degrading is exaggerated. This does not mean that desertification and soil erosion are not problems worthy of attention, only that we can be more optimistic than the usual rhetoric implies. Approaches to deal with soil degradation have to focus on reducing open access, increasing security of tenure, and improving the profitability of agriculture, thereby raising investment incentives into land improvements.

Of course, the fact that the situation is not as bad as the usual rhetoric implies does not mean that land resources can be left to themselves. Techniques for land improvements are well developed and widely disseminated and known. Their use depends primarily on farmers' incentives to apply them. For their arable land farmers need security of tenure, either within communal tenure systems, or where these are breaking down, via long term tradable leases or free hold tenure. High returns to agriculture are also needed to provide the necessary incentives to invest. Open access situation need to be avoided: Remedies require strengthening, rebuilding, or where they do not exit, building new local institutions that can control open access to all natural resources. The local institutions also require a supporting national and policy frameworks.

To sum up, a balanced view of the population challenge for African agriculture and food security therefore would stress both opportunities and challenges:

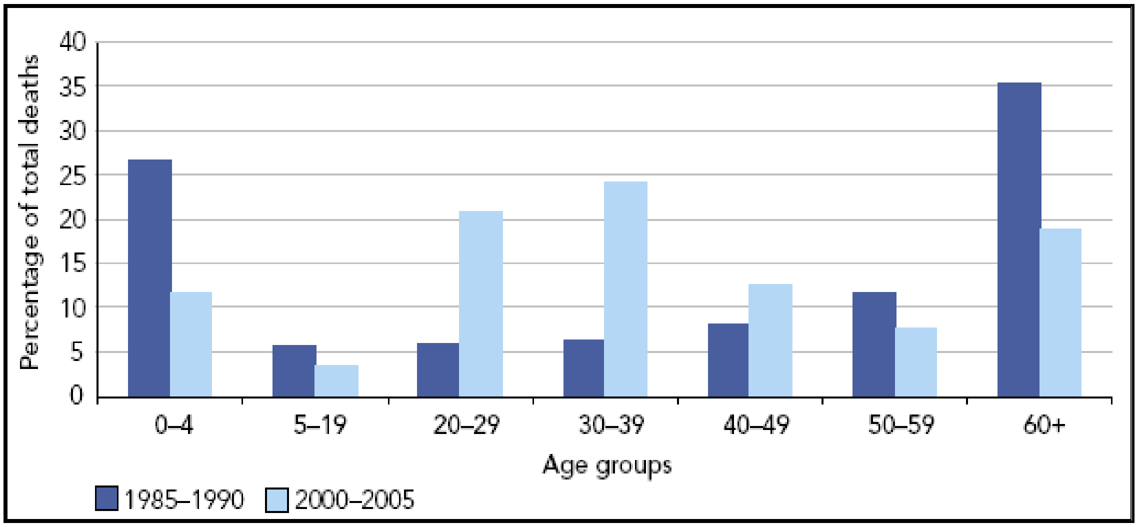
- Past population growth and high fertility rates lock in a considerable momentum of population growth that will lead to higher rural populations, extremely rapid urbanization, and high dependency rates, which in hard hit countries are accentuated by high adult mortality from HIV and AIDS.
- This not only is a drag on growth but also generates huge unemployment problems among youth; agricultural development should be seen as an opportunity to generate much more employment for rural youth and thereby help stem urbanization.
- While the demographic transition has barely begun in SSA, faster economic growth, higher female education, and a resumption of family programs could significantly accelerate it, and thereby create a population dividend for future economic and agricultural growth.
- The enormous land reserves of the continent cannot simply be harnessed by migration, but require enormous investments in infrastructure and technology. The examples from Brazil and Thailand discussed in Box 1 show that such areas can be developed and become internationally competitive. The expected higher agricultural price environment provides a major opportunity.
- Population growth, market access and higher incomes can contribute to more sustainable use of agricultural land and other resources. Local and national institutions to improve security of tenure and control open access are critical to prevent resource degradation.
- Climate change, desertification and bio-diversity losses really come together in the local government arena, communities and on the farms, requiring management and adjustment capacities. Conventions in all three areas provide financing opportunities, including the Global Mechanism hosted by IFAD, a financing instrument for the Convention of Desertification.

## HIV AND AIDS

Following the wave of infections by around a decade, the wave of deaths from HIV and AIDS is now fully upon us, leading in a number of countries to a stabilization or slight decline of HIV prevalence rates. The third wave of orphans has also started but is as yet far from its peak, with predictions that it could reach 20 million in SSA in the next decade. Rural areas are now suffering almost as much as urban areas, and maybe even more from the orphan crisis, as many orphaned urban children are returned to rural homes.

Prevalence of HIV and AIDS vary enormously across countries of SSA, for reasons which are still poorly understood. Of the 28 SSA countries with recent population-based surveys prevalence rates range from 0.9 percent in Senegal to 33.4 percent in Swaziland. Four countries in Southern Africa have prevalence rates above 20 percent, another three Southern African countries plus the Central African Republic have prevalence rates between 10 and 20 percent. Three Eastern African Countries plus Cameroon have prevalence rates between 5 and 10 percent, while the 12 countries with prevalence rates below 5 percent were mainly in West Africa plus Ethiopia (UNAIDS 2007)

**Figure 7: Age distribution of deaths in Southern Africa**




Source: World Bank, World Development Indicators, 2006

The countries of Southern Africa and the Central African Republic will experience the biggest demographic impact (Figure 7). The impact on the age structure of these countries is very adverse. In 10 years, Southern Africa went from having one-third of annual deaths coming from the working age population to two-thirds. It is unclear whether fertility will increase or decrease. But age-dependency rates will increase and thus reduce economic growth rates. In this section we will not further review the evidence of the economic impact of HIV and AIDS in general, but focus on the various interactions between HIV and AIDS, food and nutrition and agriculture. Here we summarize the findings from a literature review by Binswanger (2006).

### The Impacts of AIDS

The most dramatic welfare consequences of the epidemic are the enormous suffering of the dying person, his or her loss of life and human capital, and emotional pain suffered by the survivors.[6] The demographic literature on the impact of HIV and AIDS, in all the dryness of its statistics, concentrates on these morbidity and mortality effects, and on the consequences for the demographic composition of the affected families, communities, and countries. Because the vital statistics and the demographic and health surveys used by demographers are well developed, and combine health and demographic information, these immediate consequences of the epidemic are far better documented than the subsequent secondary impacts on the economic welfare of the survivors (Zaba et al. 2004).

Even in high prevalence countries of Eastern and Southern Africa, these deaths will not lead to a population decline. The AIDS crisis has severely increased tuberculosis and malaria infections, making these diseases much more prevalent and dangerous. The diseases are aggravated by the growing crisis of multi-drug resistant tuberculosis and increased resistance of malaria to common, inexpensive drugs. Impact estimates on economy-wide growth range from the benign to the alarming.

Whatever these impacts of HIV and AIDS may be, they have, however, not prevented the resumption of growth even in the high income countries. Impacts on agricultural output growth are still poorly understood. A few years ago it appeared that HIV and AIDS could lead to AIDS famines, especially if combined with drought. The country most studied was Malawi, but agricultural growth has now recovered, thanks to better weather, and an input subsidies program. Therefore, the fears of HIV and AIDS famines have probably been

[6] In some of the economic literature on the impact of AIDS these enormous losses seem to be of little concern, and the focus is instead on the economic consequences for the survivors. The most striking example of this neglect is the use of per capita income of the survivors as the yardstick of the economic impact of HIV and AIDS. This yardstick totally ignores the lifetime income loss of the deceased.

exaggerated. Of course, that does not mean that the high rates of mortality have no impact on food production and hunger.

The agricultural economic literature also focuses on the adaptations which household make to compensate for the losses of their members, and the speed and completeness with which they recover from these losses. Reviews of this literature and of the many remaining open research questions are Gillespie (2005 a, b), Gillespie and Kadiyala (2005), Mather et al., (2004), and Zaba et al. (2004). Therefore I will confine myself here to a few comments relevant for policy and programs to combat HIV and AIDS.

The literature on the impact of HIV and AIDS on households has suggested that the main adverse impact is labor scarcity. Helping the affected households overcome labor bottlenecks was seen as the critical issue for agricultural policy makers and researchers. The labor scarcity hypothesis arose from case studies, and from an implicit assumption that the loss of labor power associated with an adult death was more significant than losses in physical and human capital, or the pre-existing scarcity of land in poor households. However, impacted populations react in a dynamic way to their misfortune, and therefore all the issues of endogeneity, omitted variables, and disappearing individuals and households have plagued the investigators. The conclusion about the predominance of labor scarcity rested on a static view of the household, which under-estimated the capacity of households experiencing an adult death to recruit new adult members. And when looking at rural wages, it was implicitly assumed that labor demand was going to be unaffected by the death of adults, and or that there were few unemployed or under-employed workers who could replace the ones who died.

Mahter et al. (2004) used the broad survey data emerging from the Michigan state effort to analyze the hardest hit countries in seven Eastern and Southern Africa. They conclude that AIDS is projected to erode population growth roughly to zero, resulting in a roughly constant number of working age adults. Many affected agricultural households quickly recruit new adults, and the agricultural labor shortages are likely to induce urban-rural labor migration. Therefore, for poorer smallholder households, land is likely to remain the primary constraint on income growth. HIV and AIDS is likely to progressively decapitalize highly affected rural communities: and increasing scarcity of capital (savings, cattle, draft animals) may come to pose the greatest limit on rural productivity and livelihoods in these communities.

Dorward et al. (2006) show that in rural Malawi communities with high HIV and AIDS impact, widespread reduction in household incomes and increased cash constraints also tend to depress agricultural demand and the demand for rural non-tradables. This reduction in aggregate demand would reduce labor demand, and induce a fall in rural wages, posing problems for poor households who are net suppliers of labor.

Differential adjustment in household composition also affects the welfare consequences for orphans. Of course, orphans usually face serious psycho-social consequences of the loss of one or both of their parents. The consequences for their food intake and nutrition, their growth, and their school attendance depend on the households within which they are placed. Extended families are most likely to choose better-off members as the fostering parents. As a consequence, studies have shown that orphan-fostering households are not necessarily the poorest and most vulnerable households (Seaman and Petty 2005; Senefeld and Polsky 2005). But all extended families do not have enough well-off members relative to the number of orphans they need to take care of. In a meta-analysis of national nutrition and health surveys in Sub-Saharan Africa, Rivers et al. (2004) show that orphaned children, regardless of the way they were defined, were not consistently more malnourished than non-orphaned children. On the other hand, households with more than one orphan reported significantly more food insecurity and hunger than households with no or only one orphan.

In terms of impact on agriculture, the review of the large representative rural household studies fostered by Michigan State University by Mather et al. (2004) shows that the average affected rural household has similar ex-post land cultivated, total land area, cultivation rates, and total income. The ex-post comparisons suffer from the fact that the affected households may have been better off to start with. The longitudinal data set in Kenya (Yamano and Jayne 2004) shows that the death of an adult male household head is associated with a larger negative impact on household crop production, non-farmer income, and crop production than any other kind of adult death. In addition the Kenya data show that the impact of adult mortality on household welfare is more severe for households in the lower half of the per capita income distribution.

The cross section comparisons in these data sets do not support the conventional wisdom that affected households shift their cropping patterns away from high value crops towards roots and tubers. Nevertheless the longitudinal data sets for Rwanda by Gillespie (1989) and Kenya by Yamano and Jayne (2004) do show such effect for some household classes, and these effects are strongly conditioned by the gender and household position of the deceased, and the initial asset level of the affected household. The ex-post comparisons do inform on which households are likely to suffer more lasting consequences: Households with a head or spouse death have fewer ex-post prime age adults and higher dependency ratios than non-affected ones, or those where another adult died.

Few data sets adequately capture the usually prolonged period of morbidity which precedes an AIDS death. Most of the impact studies therefore concentrate on the impact of mortality. The impacts of morbidity on economic welfare (especially of women), asset depletion, agriculture, and nutrition deserve much more emphasis. So does research on strengthening community mechanisms to provide support to families who take care of the chronically ill.

#### Does better Food Intake or Nutrition reduce the Risk of HIV infection?

The huge disparity in prevalence rates across SSA, both across and within countries, has long suggested that cross country and within country environmental and biological-medical factors may be equally or more important than behavioral differences. Stillwaggon (2005) summarizes the bio-medical research on these topics: Malnutrition, combined with micronutrient deficiency (in particular of vitamin A) produces greater susceptibility to sexually transmitted diseases (STDs), particularly of the ulcerative type, and can contribute to higher viral loads. They therefore tend to increase mother to child transmission, as well as transmission among adults. Parasitic diseases such as malaria and helminthic and filarial infections stimulate HIV viral loads and increase malnutrition, and therefore correlate with risk of HIV transmission. Genital schistosomasiasis is second only to malaria in its prevalence. Because some schistosomasiasis species colonize the genitourinary tracts, it is perhaps the most important parasitic co-factor in HIV and AIDS transmission. Yet, unlike STDs, its treatment and eradication is not addressed in HIV prevention programs.

This literature does not directly show that better nutrition status reduces the rate of HIV infection in adults. The only area where such evidence exists is for mother to child transmission (MTCT). The literature suggests that micronutrient supplementation of pregnant women may improve pregnancy and birth outcomes, including neonatal child survival and birth weight (Fawzi et al. 1998; Coutsoudis et al. 1995; Kumwenda et al. 2002). In addition, multivitamin supplementation during lactation (with vitamins B, C, and E; not A) may reduce MTCT through breastfeeding, especially among women with compromised immunological and nutritional status (Fawzi et al. 2002). On the other hand, there is no convincing evidence that micronutrient supplementation during pregnancy reduced the risk of MTCT through in-utero, intra-partum and early breast feeding routes (Coutsoudis et al. 1995; Kumwenda et al. 2002).

The question is whether improvements in food and nutrition are sufficiently powerful to explain differences in prevalence rates across regions or countries. Unfortunately, there are no studies directly testing this question. However, higher socio-economic status is usually associates with better food intake and nutrition, so we look at whether higher wealth or income reduces HIV prevalence rates. However, major epidemiological studies cast doubt that such a relationship exists: Across countries in SSA, higher national income per capita, but not the poverty rate, is associated with higher prevalence rates (Gillespie et al. 2007). At the individual level, a single longitudinal study from Zimbabwe looked at the changing prevalence among men and women between a baseline from 1998-2001 and a follow up survey from 2001-2003 (Lopman et al 2007). At baseline prevalence for men and for women varied relatively little among three wealth groups. However, after adjusting for age and site type, prevalence declined faster for poor and better off women than for the middle group; it also declined faster for better off men than for middle and lower income group, suggesting that better off men were perhaps less likely to be become infected (ibid).

However, Mishra et al. (2007) used data from eight recent population-based, nationally representative surveys with HIV testing in sub-Saharan Africa, to conduct an in-depth analysis of the association between household wealth status and HIV. "This study found that, contrary to evidence for other infectious diseases and theoretical expectations, HIV prevalence is not disproportionately higher among adults living in poorer households in sub-Saharan Africa. In all eight countries included in the present analysis, wealthier men and women tend to have a higher prevalence of HIV than poorer individuals. In most cases, the positive association between wealth status and HIV is considerably diminished when a number of underlying factors (such as education, urban/rural residence, and community wealth) and some of the behavioural and biological pathways (proximate factors, such as sexual risk taking, condom use, and male circumcision) are taken into account. The results indicate that much of the positive association between wealth and HIV is caused by these underlying or mediating factors. Even after accounting for these various factors, however, in most countries wealthier adults remain at least as likely as poorer individuals to be infected with HIV, if not more."(Mishra et al. 2007, p. S25).

On balance therefore there is little support for the hypothesis that higher incomes are associated with lower incidence and prevalence. Then what explains the enormous differences in prevalence across countries and locations within countries? A four cities study by Auvert et al. (2001) compared two low prevalence cities (Cotonu, Benin and Yaounde, Cameroon) with two high prevalence cities (Kisumu, Kenya and Ndola, Zambia) to investigate the relative importance of environmental, biological-medical and behavioral factors, using samples of 1000 men and women in each city, for whom extensive blood tests, socio-economic background variables (but not nutrition) and sexual behavior variables were gathered. The study concludes that high risk sexual behavior was not more common in the high prevalence cities than in the low prevalence ones; but the rate of partner change was still contributing to HIV positive status. In the high prevalence cities men and women tended to marry earlier, and women had earlier sexual debuts; male circumcision was much more prevalent in the low prevalence cities. In addition, HSV-2 (herpes simplex) infections were much more common in the high prevalence than low prevalence cities; and HSV-2 infection was strongly associated with HIV status within all the cities and both sexes; associations with other STDs was mixed. Finally, among men, having a job was associated with higher probability of HIV infection in all cities, but there was no association with education or traveling in the past year.

The striking result of this study is that only three factors explain the largest share of difference in prevalence across cities, and being HIV positive within cities: Lack of circumcision, HSV-1 infection, and marriage (being married, having been married or marrying early). Behavioral variables do contribute to the probability of being infected within cities, but not nearly as much as the other three factors. The only one of the three socio-economic variables included that makes any contribution is whether one has a job or not. While nutrition status was not investigated, the fact that the soci-economic variables had no impact or in the "wrong" direction suggests that the nutrition factors, may not be as important in determining the spread of HIV as the literature reviewed by Stillwaggon (2005) or Gillespie and Kadiyala (2005) would suggest.

In another study in Tanzania (Bloom et al. 2002), community environmental effects were compared to individual behavior effects, using open cohort data with demographic surveillance and epidemiological surveys, as well as qualitative research. Data on the HIV and AIDS prevalence in 1994/5 and on the incidence between 1994/5 and 1996/7 among 2271 men and 2752 women were available. Adjusting for individual effects, the study found that four community factors had strong impacts on probabilities of being HIV positive: social and economic activity, ratio of bar workers per male population, level of community mobility, and distance to the nearest town. These factors were not related to differences in sexual behavior among the communities. For men, after adjusting for community effects, household assets, education, and type of work no longer mattered, while the protective effect of circumcision did. Condom use was low, but higher among those with more partners. Among men, it was associated with higher probability of infection, suggesting perhaps that it was a proxy for multiple partnerships.

Again it appears that the environmental factors, rather than individual behavior differences and socio-economic factors, are the most important ones. All socio-economic variables suggest that higher status is associated with higher risk. This again suggests that differences in nutrition could not be as important as the available reviews discussed above suggest.

#### Does better Food Intake or Nutrition prolong the Life of Infected Individuals?

In four longitudinal studies in Africa, the median survival rate after infection with HIV was estimated as between 8 and 9 years for individuals who were infected between 20-29 years of age (Porter and Zaba 2004). The largest and most reliable study of survival rates was carried out in Masaka district of Zambia, where the median survival rate was estimated at 8.6 years. Survival rates decline significantly with age at infection.

The rate observed in the Masaka study is only a little over two years less than the median survival rate of

10.9 years observed in developed countries prior to the introduction of the highly active antiretroviral therapy (HAART). The authors cite the following factors that could account for the difference between Africa and the developed world: background mortality rates from other causes than AIDS that are much higher in Africa than the developed world; the HIV-subtype (although little is known about the impact of subtype on disease progression), and the mode of transmission, which in Africa is mainly between males and females.

Other factors which could account for the difference are nutrition and morbidity from other infectious diseases. They are generally much worse in Africa than the developed world, but they are not discussed by the authors. A reason for not discussing these factors may have been that in a landmark San Francisco study of survival rates, no lifestyle factors were found to predict the rate of disease progression. Rather it was only the number of CD8 cells, and the related viral load after the first viremia following infection, which predicted the length of survival of an individual.

On the other hand, there are indications in the literature that food and nutrition status can influence survival rates in the absence of antiretroviral theraphy (ART). Energy requirements are raised by 10-30% following HIV infection in adults, and 50-100% among children experiencing weight loss[7] (WHO 2004). Nutritional support has the potential to prolong the asymptomatic period of relative health prior to the onset of AIDS (Piwoz and Preble 2000). Three different types of nutrition supplements have been considered: food rations to manage mild weight loss and nutrition-related side effects of ARV therapy and to address nutritional needs in food insecure areas; micronutrient supplements for specific HIV positive risk groups; and therapeutic foods for rehabilitation of moderate and severe malnutrition in HIV positive adults and children, but few of these interventions have been evaluated.

In a path breaking study in Tanzania, Fawzi et al. (2004) found that women who were randomly assigned to receive multivitamin supplementation were less likely to have progression to advanced stages of HIV disease, had better preservation of CD4+ T-cell counts and lower viral loads, and had lower HIV-related morbidity and mortality rates than women who received a placebo. Vitamin A appeared to reduce the effect of multivitamins and, when given alone, had some negative effects. The authors concluded that multivitamin supplements delay the progression of HIV disease. They and provide an effective, low-cost means of delaying the initiation of antiretroviral therapy in HIV-infected women.

We therefore have a major puzzle: Both nutrition and a variety of infectious morbidities have been shown in the reviews of Stillwaggon (2005) and Gillespie and Kadiyala (2005) to be potentially important factors influencing survival rates. And vitamin supplementation has in some cases also been shown to be beneficial for survival. But the survival studies leave little room for major impacts of these factors, as the rates in the developing World are too similar to the developed country rates, and background mortality alone is likely to explain a lot of the difference.

### Interventions against HIV and AIDS in Rural Areas

We have seen that agricultural and food and nutrition interventions are not likely to be powerful interventions against the spread of the disease or the progression of an infected individual from infection to death. Instead direct prevention interventions are required, and making ART widely available in rural areas. On the other hand, agricultural and food and nutrition interventions are likely to be important in mitigating the impact of the disease on affected households, especially those with more than one orphan, households headed by women and grandmothers, and children headed households. And better and more food may also

[7] Energy requirements are likely to increase by 10 percent to maintain body weight and physical activity in asymptomatic HIV-infected adults, and growth in asymptomatic children. During symptomatic HIV, and subsequently during AIDS, energy requirements increase by approximately 20 to 30 percent to maintain adult body weight. Energy intakes need to be increased by 50 to 100 percent over normal requirements in children experiencing weight loss (WHO 2004).

help the adherence of patients to ART.

A major difficulty for HIV and AIDS interventions in rural areas is that in *each of the areas of prevention, care and treatment, and mitigation, a number of activities are required*. This means that intervention programs are complex and involve several sectors and actors. Where interventions must become available to all populations, service delivery approaches relying on specialized government implementing agencies or NGOs, who each focus on one or a small subset of components of the required interventions, will not be scalable in rural areas. The main reasons for this are that (1) delivering a multiplicity of services via specialized providers in separate programs would lead to very high overhead and transport costs, and (2) in widely dispersed rural areas, holistic and multi-sector interventions can only be coordinated at local levels and implemented by the communities themselves.

*Prevention:* If people can be convinced to change their behaviors, and either abstain from sex or use condoms, they will be protected from infection. This is so regardless of the factors determining prevalence in any given environment, and regardless of the fact that it is not differences in behavior which determine prevalence rates. In rural areas of Africa, interventions not only require inter-personal communication, but participatory involvement of whole communities, such as the model of the Tanzania-Netherlands Project to Support AIDS Control (TANESA), which was scaled up to all villages in the entire Mwanza district. Therefore all rural development interventions should be designed to contribute to mainstream HIV and AIDS prevention efforts. This does not necessarily have to be a costly effort, as most rural development programs already strengthen community institutions. These can then be entrusted with the task. Mainstreaming HIV and AIDS prevention certainly should receive equal emphasis as other mainstreamed agendas, such as improving gender relations and the management of natural resources.

*Treatment:* The World Health Organization (WHO) guidelines for HIV and AIDS treatment, including ART (WHO, 2004) have been designed in such a way that a nurse in a rural health post, without laboratory equipment, can use syndromic management (i.e. diagnosis based solely on observable symptoms) to diagnose advanced HIV disease and prescribe a standard first line treatment to adults. The WHO guidelines recommend the strong involvement of communities in the provision of other components, such as training in healthy living and survival skills, provision of food and nutrition, and adherence support. FAO therefore needs to closely follow what is happening in terms of the scaling up of AIDS treatment in rural areas, and work with WHO on analysis and guidance for successful programs.

*Care and support:* Care and support involve psycho-social support, health care, home-based care, education, food and nutrition interventions, as well as livelihood support. The consensus of the literature is that care and support should take a holistic approach to the needs of affected families and individuals, rather than dealing with sector-specific interventions one at a time too hard to find, but common knowledge. However, very few holistic and community-based care and support initiatives have been scaled up beyond the level of small boutiques. We have seen that HIV and AIDS impacts are highly differentiated according to who is sick or dies in a family, how well off the household was before experiencing the impacts of HIV and AIDS , and how large and well off its extended family network is. Therefore, only a fraction of the affected households and individuals need care and support interventions from the outside. A better way to provide care and support in a holistic and multi-sectoral way in rural areas would be to design and financially support more general community-driven social safety nets, which would focus on all highly vulnerable households and individuals, irrespective of the source of their vulnerability. Box 3 presents a proposal for such a program.

The high prevalence of AIDS stigma means that it is rarely possible to provide care and support interventions only to families and individuals affected by HIV and AIDS. And why would one want to direct support only to families who have chronically ill HIV and AIDS patients, rather than all families with chronically ill patients? Or only to HIV and AIDS orphans, rather than just orphans? Care and support to HIV and AIDS orphans should therefore be approached within broad community-driven social protection programs.

## KEY CHALLENGES OF AGRICULTURAL GROWTH, RURAL POVERTY REDUCTION, AND HUNGER

Neither population growth nor climate change will present insurmountable challenges to agricultural development in Africa, if Africa seizes the opportunities it now has. And both provide opportunities. Reducing the death and suffering from HIV and AIDS requires generalization of prevention, treatment and care and support in rural areas, taking advantage of agriculture in the care and support area.

But there are other serious threats to the agricultural growth rate, and the reduction of poverty and hunger: Among them are the widening technology divide, slow development of input and output markets and the associated smallholder services, inadequate safety nets to deal with extreme poverty, risks and fluctuations, and the imperative of regional initiatives for agriculture. A number of additional important challenges are covered in Binswanger-Mkhize and McCalla (2008): Biofuels, the supermarket revolution, security of access to resources, land administration and land reform, gender equity, fisheries and forestry, investments in rural infrastructure such as rural roads, and irrigation. In the following, a number of these challenges are discussed in greater detail.

### The Growing Technology Divide

Around 1961, average cereal yields were around 1 ton per ha in the developing world, and rose to nearly 3 tons per ha by 2005. They increased to around 4.5 tons in East Asia and the Pacific (EAP), to around 2.3 tons in the Middle East and North Africa (MENA), while they stagnated around 1 ton in SSA (World Bank 2007). In 2000, improved varieties covered 84 percent of the cereal area in EAP, 61 percent in MENA and Latin America and the Caribbean (LAC), while they covered only 22 percent in Africa. In 2002, fertilizer consumption had reached a staggering 190 kg per ha of arable and permanent crop land in East Asia and the Pacific, 73 kg in MENA, but only 13 kg in SSA. As a consequence, even the penetration of high yielding varieties led only to very limited yield growth in SSA.

Agricultural growth in SSA has primarily been a result of area expansion, rather than productivity growth in crops and livestock. This is not that surprising, because Africa has the largest agricultural land reserves in the world. Using soil, land cover and climatic characteristics a FAO study has estimated the potential land area for rainfed crops, with a total potential increase in rainfed agricultural land for the whole of Africa of about 300 million hectares. However these land reserves are very unevenly distributed across sub-regions and countries, with some countries already having very high population densities. Even where area expansion remains a major avenue for agricultural growth, it would be much more profitable if productivity were higher.

The challenges of productivity growth are higher in SSA than in other regions of the world: There are more different environments to deal with, more crops, and more crop and livestock pests and diseases than elsewhere. There are no dominant farming systems that extend over very large areas such as irrigated rice and wheat in Asia. Irrigation infrastructure is poorly developed. Climate change will significantly add to the technology challenge. As a consequence of these factors, Africa is less able to borrow technology from other tropical countries; and technology transfers between regions in Africa are also constrained.

In 2000, global agricultural research and development (R&D) spending was 36.3 billion US dollars, of which 37 percent was conducted by the private sector, while 63 percent, or about 23 billion US dollars, was conducted by public entities. Ninety three percent of private research was conducted in developed countries (all figures from Pardey et al. 2006). On the other hand, public agricultural R&D grew faster in the developing world, and is increasingly concentrated in China, India and Brazil. In stark contrast, public agricultural research in SSA grew at only about 1 percent per annum in the 1990s, and in 2000 was around 1.6 billion dollars. SSA has the lowest share of private agricultural R&D spending in the World, only 1.7 percent of already low public spending (ibid). Of total agricultural research spending, donors provide about 40 percent, and in some countries this rises to 60 percent. Only five African countries — Nigeria, South Africa, Botswana, Ethiopia, and Mauritius — are paying the recurrent budget of their national agricultural research system (NARS) from national sources. "Collectively these data point to a disturbing development—a growing divide regarding the conduct of [agricultural] R&D—and, most likely, a consequent growing technological divide in agriculture. (…) The measures also underscore the need to raise current levels of funding for agricultural R&D throughout the region while also developing the policy and infrastructure needed to accelerate the rate of knowledge creation and accumulation in Africa over the long haul." (ibid, p. 68).

*The changing nature of technology discovery:* All around the world innovation is shifting away from a linear pattern that starts with scientific discovery and moves successively to technology development, adaptation to local conditions, and dissemination to farmers. In its place comes a broader and more circular paradigm: It is broader in the sense that innovations no longer concentrate on basic food or industrial agricultural outputs, but instead include the entire value chain from farm production, natural resource management, assembly, processing, marketing and retail to consumers. Driven by consumer demand changes, attributes of appearance, convenience, nature of the production process (organic, environmentally friendly, genetic and location origin) are assuming importance, most strongly so in developed countries, but increasingly in middle and low income countries. The growth in information and communications technology has transformed the ability to take advantage of knowledge developed in other places or for other purposes. Within this broader paradigm, private research and development plays an increasing role, facilitated by the development of broader intellectual property rights in agricultural technology which provide many promises but also induce high levels of anxiety about exclusion and high transactions costs for developing country agricultural innovation. A number of larger developing countries are taking advantage of greater private sector involvement, including most recently India which now boasts over a hundred private domestic and multinational seed companies. The private seed sector is also growing in Africa, with Kenya being perhaps the most advanced.

*Biotechnology and the Privatization of Agricultural Research*

Farmers have been genetically modifying plants and animals for 5000 years or more, and agricultural scientists have joined them ever since the Mendel revolution in the 19th century. Biotechnology (BT) includes a number of techniques, the most powerful is the development of trans-genic crops and animals. The controversial issue is only whether it is appropriate to transfer genes from one species to another. Evenson and Raney (2007) address these political and scientific issues. Among the developing countries, China and Brazil, followed by India, have invested significantly in agricultural biotechnology. On the other hand, the Consultative Group on International Agricultural Resear (CGIAR) system is spending less than 10 percent of its overall budget on BT research, perhaps because of resistance of important European donors. The great success of Bt cotton and the prospects of nutritionally fortified rice and other crops have taken some of the wind out of the sails of environmental critics. Bt cotton has resulted in dramatic reductions in pesticides use wherever it has penetrated, as well as higher yields and incomes of small farmers, and no observable adverse environmental consequences. Biotechnologies are regulated from the point of experimentation, to field trials, and ultimate release. Further regulations govern where and how the crops may be grown, and how and where the products may be sold.

As part of its effort to bridge the technology divide, it appears that Africa urgently needs to take advantage of the many possibilities that biotechnology holds. Eicher et al. (2006) review biotechnology development for six food crops and cotton in Africa, and find unexpected scientific, legal, economic and political barriers to the development of GM crops and long delays in developing and implementing national bio-safety regulations and guidelines. They unfortunately conclude that with the exception of Bt cotton, most genetically modified crops are at least 10-15 years from reaching smallholders in Africa.

The Acceleration Phase of the Molecular Biology Revolution*:* The potential of rapidly expanding knowledge of genomics and our increased capacity to modify useful plants and animals is just at its beginning and can become an important factor in adaptation to and mitigation of climate change, desertification, increasing resource scarcity and threats from pests and diseases. Possibilities for building in stress resistance (drought, heat, and cold), immunity to pests and diseases, and improved nutritional values, as well as manufacturing pharmaceuticals in plants, which 20 years ago were wild dreams, are now much closer to reality. For example, Monsanto and BASF have just announced a 1.5 billion US dollars research and development partnership using biotechnology research. "Focus of efforts will be on the development of higher yielding crops that are more tolerant to adverse environmental conditions such as drought." (CropBiotech Update 23 March 2007). But will these developments occur fast enough to bridge the widening technology gap of Africa?

The answers will come mainly by private sector proprietary research with intellectual property protection. The fundamental question is how the benefits of biotechnology can accrue to small African farmers in a world of privatized research. There also remain major public goods issues:

- *Conservation of global genetic resources:* Significant progress has been made on issues of preservation, conservation, access, ownership and returns from genetic modification for the 64 plant varieties under

the International Treaty on Plant Genetic Resources (ITPGR); but what about the rest of the rest of the plant kingdom, including forests, animals, fish, and critical microbial life?
- *Bio-safety protocols:* While rules and regulation regarding the development and testing of genetically modified organisms (GMOs) are clearly national policy issues, competing and conflicting paradigms between North America and Europe put small developing countries at the mercy of large trading blocks when they attempt to decide whether they want to develop, import or consume GMOs. Can FAO help countries in Africa develop the necessary rules and decision processes?
- *Access to promising genetic materials and techniques:* Current estimates suggest that six multinational firms dominate molecular genetic research on plants and animals. These firms include Monsanto, Syngenta, BASF, Bayer, Dow AgroSciences and Dupont. The challenge is to find ways these firms can share promising technologies with developing countries without compromising their legitimate right to garner profits from their investments in discovery. The Danforth Plant Science Center maybe one example. The African Agriculture Technology Foundation (AATF) discussed below is another model. But eventually regional research organizations must acquire the capacity to participate as peers as the molecular biology revolution plays out.

Even where gene technology is donated, there may be slow progress. Can Africa afford to be left behind China, India, and Latin America. Should it adhere to complex regulations dictated by others? Rather it should insist on more streamlined approaches. Whatever the answer to the above questions, biotechnology approaches must be nested and integrated into plant breeding programs. Special attention should be given to raising public awareness of and political support for biotechnology, and commitment to strengthening African capacity in biotechnology, biosafety, food safety and intellectual property rights, and the training of the next generation of African plant breeders and GM crop specialists

### *The African Institutional Framework for Agricultural Technology Generation*

Sub-Saharan Africa has over 400 public and private entities engaged in agricultural research, of which nearly 200 are public research institutions, and another 200 are universities (compared to 20 in 1960). However, 40 percent of them have fewer than 5 researchers and 93 percent have fewer than 50 full time researchers (Beintema and Stads 2004). Sub-Saharan Africa has nearly 50 percent more agricultural scientists than India and about a third more than the United States, but all of SSA spends only about half of what India spends and less than a quarter of what the United States spends on agricultural R&D. Only a quarter of African scientists have a PhD, compared with all or most scientists in India and the United States.

All institutions engaged in research within each country are collectively aggregated into NARS. In the different sub-regions of Africa the NARS have created Sub-Regional Organizations (SROs), the strongest of which are CORAF/WECARD for West and Central Africa and ASARECA for Eastern and Central Africa. The SRO for Southern Africa is the SADC Food Agriculture and Natural Resource Directorate (SADC/FANR), and a North Africa SRO initially comprising Morocco, Algeria, Tunisia and Libya is also under development. The SROs foster research collaboration in their sub-Regions. ASARECA and CORAF/WECARD have established research grant funding mechanisms of their own, with significant support from the European Union (FARA 2007). In 2001, the three SROs for sub-Saharan Africa established the Forum for African Agricultural Research (FARA) that has its secretariat at the regional FAO office in Ghana. FARA has been entrusted by the African Union and the New Partnership for African Development (NEPAD) to coordinate Pillar 4 of its Comprehensive African Agricultural Development Program (CAADP) which focuses on agricultural research and technology dissemination.

In order to strengthen bio-technology research, four regional biosciences networks initiatives were established under the auspices of the NEPAD. The Biosciences eastern and central Africa Network (BecANet) facility was established in 2004. BecANet consists of a secretariat and hub located on the campus of the International Livestock Research Institute (ILRI) in Nairobi, Kenya (that should provide a common biosciences research platform, research-related services, capacity building and training opportunities), regional nodes, and other laboratories distributed throughout eastern and central Africa for the conduct of research on priority issues affecting Africa's development. In addition NEPAD has initiated three other African Biosciences Initiative which are networks of leading centers and consist of hubs and nodes in Northern, Southern and Western African, i.e., the Southern African Network for Biosciences (SANBio) with its hub at the Council for Scientific and Industrial Research, Pretoria, South Africa; the West African

Biosciences Network (WABNet) with the hub at Institute Senegalais de Recherches Agricoles in Dakar, Senegal, and the Northern Africa Biosciences Network (NABNet) with the hub at National Research Centre in Cairo, Egypt. These hubs possess and are strengthening the necessary physical infrastructure to develop and implement regional and continental biosciences projects (NEPAD, 2007a).

In the early 2000s a public-private sector partnership to foster access to proprietary research was created, funded by the Rockefeller Foundation. The AATF is an international not-for-profit organization designed to facilitate and promote public-private partnerships for access and delivery of proprietary technologies that meet the needs of resource-poor smallholder farmers in SSA. Through a catalytic and facilitative role, AATF tries to serves as an honest broker between owners and/or holders of proprietary technologies and those that need them to promote food security and improve livelihoods for smallholder farmers in SSA. AATF was incorporated in the UK in January 2003 and in Kenya in April 2003.

*The Consultative Group on International Agricultural Research (CGIAR)*

The CGIAR supports the research of 15 international Centers, of which 13 are located in developing countries. In 2006 the CGIAR consisted of 1,115 internationally recruited scientists and a total staff of 8,154 working in over 100 countries. A strategic component of the system is the ex-situ germplasm collections of eleven of the International Agricultural Research Centers. Building on earlier independent initiatives, the CGIAR since the early 1990s, has rapidly broadened its focus from crop genetic improvement towards natural resource management, environmental issues, and policy research.

In 2006, of total CGIAR expenditures of 458 million US dollars, around 220 million US dollars, or 48 percent, went to SSA. Note that this is only about 10 percent of total research spending in SSA. Africa also benefited from the share of 9 percent share of CGIAR expenditures that went to North Africa and Central and West Asia. All Centers currently have programs in SSA. Two Centers are located in West Africa (IITA and WARDA), while two are in Eastern Africa (ILRI and ICRAF). There were a total of 162 CGIAR Centers' programs/projects in SSA in 2006. To implement these programs/projects, the Centers engaged a total of 389 internationally recruited staff, 121 regionally recruited staff, and 2607 local staff. However, as discussed previously, the CGIAR spends less than 10 percent of its overall resources on biotechnology research, and little of that is likely to be spent in or for Africa. The CGIAR is not the only set of advanced research institutes operating in or for Africa. France's Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD), and the Institut de Recherche pour le Développement (IRD), formerly Office de la Recherche Scientifique et Technique Outre-mer (ORSTOM), also have operations on the continent. The combined budgets of these two institutes are as large as the entire CGIAR budget (NEPAD 2007b).

CGIAR research has made significant contributions to SSA agriculture. Many previous studies highlight successes such as the high-yielding cassava varieties that include resistance to mites, mealy bugs, cassava bacterial blight, tolerance to drought, low cyanogens potential, and good cooking quality; the famous biological pest control especially in cassava but also in other crops; biological pest control in potato, including via pest resistant cultivars; improved hybrids and open-pollinated varieties of maize in western, eastern and southern Africa; higher-yielding wheat in eastern and southern Africa; hybrid sorghum in Sudan; semi-dwarf rice for irrigated regions in West Africa; early maturing cowpeas in West Africa; and disease-resistant potatoes in the eastern and central African highlands.

**Box 2: Estimated rates of return to investment in agricultural R&D**

| Region | Number of estimates | Median rate of return |
|---|---|---|
| Africa | 188 | 34 |
| Asia | 222 | 50 |
| Latin America | 262 | 43 |
| Middle East/North Africa | 11 | 36 |
| All developing countries | 683 | 43 |
| All developed countries | 990 | 46 |

Source: Alston et al. (2000)

The adoption of new crop varieties in Africa has been significant. In the late 1990s the adoption rate of improved varieties of all crops was 22 percent of total area planted, and of this 11 percent was planted to CGIAR related varieties, usually produced in collaboration with the NARS. (Pardey et al. 2006 table 6). In eastern, central and southern Africa 10 million farmers are reported to plant and consume improved varieties of beans.

Alston et al. (2000) assembled more than 1500 rate of return estimates to agricultural research and extension (Box 2). The median of the rate of return estimates was 48.0 percent per year for research, 62.9 percent for extension studies, 37 percent for studies that estimated the returns to research and extension jointly, and 44.3 percent for all studies combined. Box 2 shows that the median return in the developing World is about the same as in the developed World, and that the median rate of return in Africa is slightly lower than elsewhere, but still very high at 34 percent.

Evenson and Gollin (2003) estimate CGIAR contributions to yield growth due to CGIAR research in SSA to be in the range of 0.11–0.13% per year. This range is much smaller than the 0.30–0.33% per year average yield growth across all developing regions (Evenson and Gollin 2003). Despite substantial introduction of new varieties there has not been a great aggregate impact on yields, compared with other regions, partly because of the much lower adoption rates and partly because of lack of irrigation, fertilizer, and inappropriate policies.

*The most urgent need for action*: The upshot of the discussions on the institutional framework and the returns to research is that the under-investment in agricultural research in Africa is not warranted either by low returns or low adoption rates. FARA has developed the Framework for African Agricultural Productivity (FAAP) that sets out guiding principles for how research is to be fostered, institutionalized and financed in Africa (FARA 2006). Under FAAP, FARA, the SROs, and the NARS will collectively guide the evolution and reform of agricultural institutions and services; foster an increase in the scale of Africa's agricultural productivity investments, and help align and co-ordinate financial support.

A joint donor evaluation analyzed FARA and its programs as follows: "FARA is a young organization (…) it has developed a strong organizational framework in its first three years of full existence. The Secretariat has demonstrated that it is both efficient and effective in its operations (…) with increasingly significant tasks being assigned to the FARA Secretariat and the various FARA constituencies, these (…) urgently need to increase their human resource capacity. (…) JEE believes that the FAAP provides a framework for harmonizing donor support, and that committing to consolidated funding of the FARA Rolling Work Programme & Business Plan [RWPBP] is the best means of pooling resources." (FARA 2007a, p.11).

*Despite these favorable developments and external assessments, the work programs of FARA, of the SROs and of the NARS remain seriously under-funded.*

### *Misallocation of Limited Research Resources*

The limited research resources also seem to have increasingly misallocated. Given the heterogeneity, the poor borrowing opportunities, and the enormous challenges from pest, diseases and water stress, basic innovations at the science level are urgently needed in a wide variety of crops and livestock diseases. Yet, the proportion of research going to basic sciences has been declining in national and international research systems alike. Instead the resources have gone to agronomic and farming systems and environmental research that has little record of high rates of return. The African Challenge program continues the same unfortunate trend. Scarce scientific resources have also been diverted to implementation of programs, rather than research. While Africa has created not less than four regional centers for biotechnology, these remain severely underfunded. The blame for these factors may lie primarily with donors impatient for immediate results, or distracted by donor fashions. Despite their commitments to the CAADP agricultural priorities, national governments have also not significantly increased their funding for agricultural research in general or biotechnology in particular. They also have invested little in biotechnology capacity, probably for political reasons. In the meantime India, China and Brazil are sharply increasing their investments in biotech research.

There is some relief in sight. AGRA intends to fund training of 1000 plant breeders. However, unless they can be posted in better funded institutions, the best of them will be lost to emigration. Private sector technology research has grown considerably, albeit less than in Asia and Latin America. Nonetheless, unless the science base improves, the gains from conventional breeding in the public and private sectors may be insufficient to close the growing technology divide. The Bill and Melinda Gates Foundation, a founding member of AGRA, has is also invested in basic research in a number of crops, but given the enormous needs, the funding remains inadequate. There is therefore little hope that the crisis of the growing technology divide will see any rapid solution, unless African governments muster the political will to sharply increase the necessary agricultural science funding.

#### *Agricultural Science and Education Institutions*

"Africa now houses roughly 300 Universities. Three quarters of African countries offer some tertiary level training in agricultural sciences. At least 96 public universities teach agriculture and natural resources management. Of these, 26 are in Nigeria, 10 in South Africa, six in Sudan, five in Kenya and three in Ghana. Nineteen separate faculties of veterinary science exist in 13 countries, five of them in Nigeria alone"(Johanson and Saint 2007, p. 15). Despite these many facilities, agricultural aid funding "…has dropped precipitously. … agriculture received a diminishing portion of a shrinking development assistance pie…" Country expenditure has paralleled the drop in donor assistance. What is left is a proliferation of institutions which have limited staff with virtually no research support money. The sad part is that now the need for agricultural technology development has regained high priority for Africa, the continent is left with a deteriorating, oversized and fragmented infrastructure, many vacant positions, an aging staff, outdated equipment, and no operating funds (Johanson and Saint p 34).

Johanson and Saint's conclusion is poignant; "Agricultural education and training has been demonstrated to be a vital, but much neglected, component of agricultural development in Africa. It is *under-valued, under – resourced and under-provided*. Human capital in agriculture has been depleted by long neglect." (p. 67). The InterAcademy study states "(…) It is the conviction of this study panel that much of what would be necessary to improve agricultural productivity and food security in Africa hinges on strengthening agricultural educational systems, more specifically the coverage and quality of higher education." (p. 184)

However there are hopeful signs. "Seven American foundations have formed the Partnership for Higher Education in Africa and pledged to invest at least USD 200 million over the next five years (…) and (…) the Gates and Rockefeller Foundations recently formed a separate partnership, called the Alliance for a Green Revolution in Africa (AGRA)" (ibid). UNDP is supporting a community of practice, SEMCA – "Sustainability, Education and the Management of Change in Africa" focusing on agricultural education.

In conclusion of this science and technology section, it is clear that African regional and national institutions for agricultural science, technology and agricultural science education have started to respond to the enormous scientific and technological challenges faced by Africa. The challenges are intensified by increasing competition for resources, climate change, and rising international agricultural prices. These responses are occurring in a rapidly changing global research system including bio-technology, intellectual property rights and patent systems, and a growing range of players, especially the private sector. The significant institutional responses have not so far been matched by adequate funding from international donors and national governments, especially in the areas of bio-technology and science education.

### Smallholder Services and Input and Output Markets

Improvements in technology will continue to lead to lower productivity gains, if services, inputs and output markets are not significantly improved. Rural finance is also insufficiently developed. Farmers' organizations have made a lot of progress, but are still not able to provide much of the needed capacity. If smallholder services, rural finance, and markets were improved, however, a number of problems will be closer to a solution: Farm profit and investments will increase, nutrition depletion will be reduced, and food insecurity associated with poor markets will be reduced. The re-conquest of domestic and regional markets will then also be closer at hand. Again, relying on donor finance for these improvements will not be sufficient to solve these problems. Political will on the part of African governments is needed to provide the necessary finance.

### Safety Nets

While emergency relief is relatively well developed in SSA, safety nets for the very poor are not, again in sharp contrast to India and China. For example, less than 1 in 100 orphans receives any kind of assistance in

SSA (other than South Africa). While South Africa has a number of conditional grants programs for the aged, children, and the disabled, few other SSA countries are experimenting with them. Support to traditional safety net mechanisms in rural communities is conspicuous by its absence. And few employment generation programs have more than spotty coverage. But the need for safety nets will not be reduced by growth or agricultural growth. Such growth tends to bypass the very poor and destitute. The population of old people without family support will go up with population growth and improving incomes and health. Climate change, HIV and AIDS, malaria, tuberculosis, and the growing orphan crisis require better safety nets. Growth is increasing the fiscal space of African governments and they need to take advantage of it to improve the safety nets.

In SSA, South Africa, Botswana and Namibia have developed significant cash transfer mechanisms to assist a number of the most vulnerable groups, the aged, the disabled, children, and people living with HIV and AIDS. These operate in both rural and urban areas. Financing such cash transfer programs may be beyond the reach of many of the poorest countries. Alternatives are to strengthen traditional community safety net mechanisms along the lines discussed in Box 3.

**Box 3: A Burkina Faso Proposal for Scaling Up Social Protection**

Communities and individual families are already part of an informal, if inadequate, social protection system. But they do need additional resources and support to expand these informal mechanisms into a more systematic effort, and to finance support to education, health care or home based care, etc. These resources should be provided as matching grants to the communities, with the latter providing the matching resources in cash or in kind, for example food needed for the most vulnerable.

While communities all over Africa are able to identify vulnerable families, and classify them by degree of need, they are not able to carry out proper needs assessment for these families, a task which normally is done by a social worker. In Sanmatenga there are nearly 300 villages and urban neighborhoods, but only three trained social workers, and there is no way the Ministry of Social Welfare can hire enough social workers to assist communities to do this job. Just as in the areas of agricultural extension, health, or veterinary medicine, it would therefore be necessary to develop a system of community-based social workers. Communities should select one or several members to be trained in basic family needs assessment and supervision skills, and they could then be remunerated via daily allowances for their work out of the community grants. The Ministry of Social Development would need to develop a curriculum, training program, and supervision program for them.

Assisting the chronically ill, orphans and the families which take care of them will require significant additional training of enough community members to manage the tasks. These community members cannot work as volunteers for a long period of time, and need to be provided with modest remunerations, such as per diems for every day they work or home visit they make.

The community members will encounter situations which they and the community as a whole cannot handle, such as medical emergencies, or child abuse. To deal with these cases requires the putting in place of proper referral systems so that difficult cases can be handled by health professionals, social workers or educators with the required skills. These same specialists need to be involved in designing and delivering the training and be available for facilitation and training on demand.

The same committee structures that were used for prevention at the provincial, district, and community level, the same training teams, and the same financing mechanisms can be reinforced and used to coordinate, manage and monitor the social protection program. In particular the committees can coordinate and provide financial resources to the NGOs and local offices of the respective government services so that they can become the facilitators, trainers and referral system.

Source: Hans Binswanger-Mkhize, personal observations

### The Imperative of Regional Cooperation in Agriculture

Throughout this paper many critical issues were encountered that can best be, or only, solved by regional action, and more are yet to come; let's recall a sampling:

- Small countries dominate the African scene often lacking financial capacity for public goods investments;
- Small land locked countries generally do worse, and depend on regional integration to be able to do better
- Expanded regional trade in agriculture and food products is good for growth, farmer's income and regional foods security; the short run management challenges of the current food price spike and the long run opportunities arising from prices that are expected to settle at higher than past levels only add to this imperative
- Expanded regional trade and food security will be helped by the harmonization of standards and sanitary measures, and sub-regional and regional capacities to implement them;
- Freer borders and internal infrastructure should encourage private sectors traders;
- For small countries, regional infrastructure –roads, communications, ports – critical for access to each other and external markets;
- Reversing land degradation and desertification and preserving biodiversity require trans- boundary collective action;
- Managing crucial, but under threat, forestry and fisheries resources must be approached on a transnational basis;
- Defense against plant and animal disease epidemics require collective responses at sub-regional and regional levels;
- Success in agriculture crucially depends on indigenous scientific capacity to generate new technology; given small and poor countries is far better done on a regional or sub regional basis – FARA and the SRO's are on the right track but the effort needs to be greatly expanded;
- Biotechnology research is expensive with a large critical mass therefore two or three regional institutes is far superior to 48 or 24 underfunded, under resourced national institutions;
- Indigenous scientific capacity requires trained people, again better done by regional institutions which have critical mass and necessary financial support;
- Regional approaches to rural financial architecture may increase potential deposits and loanable funds and spreads risk.

These examples hopefully are enough to illustrate that the potential for regional approaches and an overall regional strategy for rural Africa are significant. *In most of these areas institutional development programs have been created. Yet they remain massively underfunded. The main reason for this is that the regional efforts produce regional and sub-regional public goods, and therefore their financing is subject to the familiar free rider problem of financing public goods. Except the largest countries which have an incentive to supply themselves with these regional public goods, countries will seek to benefit from the investment of others. Better coordination of funding by African countries, as well as external co-finance, could help overcome the underfunding. But donor finance remains both insufficient and unreliable for the task. The African Union, via the CAADP, the Economic Commission for Africa, and African Development Bank need to coordinate these efforts.*

## CONCLUSIONS

African agriculture today faces a context of general economic growth in Africa, and in the medium term a brighter market outlook in international, regional and domestic markets than anytime in the last 40 to 50 years. Both macro-economic and sector policies are more favorable, although African farmers still face the worst agricultural incentives in the World. In most countries the institutional environment has also given local governments, communities and the private sector much more opportunities than in the past. And business climates are improving, albeit from a very low level. The smallholder dominated agricultural sectors of Africa have already responded in terms of a significantly higher growth rate.

Improved market opportunities will arise in traditional as well as non-traditional agricultural exports and they need to be seized. At the same time domestic and regional markets will present the most promising area for medium to long term agricultural growth. That means that small farmers, despite the supermarket revolution and rising international quality standards, will be well placed to seize them.

While climate change is likely to affect most regions in Africa negatively, it will also open new opportunities in some regions where rainfall and other climate parameters will improve. Other opportunities arise from the possibility of carbon trade once the instruments for trading via land use commitments and changes are better developed. In the aggregate the impact on African agriculture will undoubtedly be negative, but climate models are not yet sufficiently well developed for Africa to predict what will happen with sufficient certainty to engage in detailed planning. As a consequence, climate change should be mainstreamed into the general agricultural and risk mitigation agendas. In particular much better capacities for agricultural technology development are needed.

Population growth is not yet slowing sufficiently fast to provide for a population dividend. At the same time the evidence for a generalized negative impact of population growth on agriculture is lacking, and instead in many areas population growth, combined with good market access has led to beneficial agricultural intensification.

HIV and AIDS has led to an enormous human tragedy and a reduction in growth prospects in hard hit countries. Agriculture and food interventions can help in mitigate the impact in rural areas. But neither prevention nor treatment programs have yet been scaled up adequately in rural areas, despite the fact that how to do that is well known, and scaling up of these interventions remains the most pressing issue.

The most neglected aspect of the agricultural agenda in Africa has been agricultural technology, and as a consequence the continent faces a growing technology divide. The continent has a large number of agricultural scientists, research institutions, and agricultural education and science education establishment. But these are mostly too small, donor dependent and underfunded. As a consequence Africa is not only lagging badly in traditional approaches to plant breeding and animal disease control, but is at great risk of missing the boat in the biotechnology revolution. Unless Africa, like China, India and Brazil, starts investing more of its own resources into agricultural science, science education and research, the huge existing technology divide will only deepen.

The agenda for action arising from the analysis of this paper is not new. The four most important among them are as follows:

1. Avoid backsliding on economy-wide and agricultural policies and further reduce agricultural disprotection in countries and commodities that still practice it.

2. Reduce barriers to intra-regional trade in food and other agricultural commodities and properly finance the regional institutions that support regional trade, quality and phytosanitary controls, and other regional agricultural public goods and services.

3. Sharply increase domestic and regional funding of agricultural science, science education, and research, and the associated centers of excellence; and thereby regain the technology agenda from the donors and pull them along in increasing their funding of priority areas.

4. Assist in the deepening of domestic markets and foster sharp improvements in smallholder services

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# CAN THE SMALLHOLDER MODEL DELIVER POVERTY REDUCTION AND FOOD SECURITY FOR A RAPIDLY GROWING POPULATION IN AFRICA?

**Steve Wiggins***

## SUMMARY

Despite the achievements of smallholders in Asia during the green revolution, there is scepticism that Africa's smallholders — who dominate the farm area in most countries — can imitate this model and deliver agricultural growth. This paper assesses whether such pessimism is justified.

Given the high transactions costs of hiring labour of farms, diseconomies of scale can be expected when labour is relatively cheap and abundant compared to other factors of production: which may explain the survey evidence that small farms often produce more per hectare than larger farms. In conditions of low development with relatively cheap labour, small units may have advantages over larger ones.

The empirical record of performance of small and large farms in Africa is uneven and incomplete. Given the dominance of small farms in agriculture in many African countries, national data may be indicative of small farm performance. The record since the 1960s shows variable performance in agricultural growth through time and space, with slow growth in the 1970s followed by acceleration from the early 1980s. Even more striking is the difference in the performance of Northern and Western Africa compared to that of other regions of the continent. But the differences are not just regional: there is great variation across countries. While many African countries have a disappointing record of growth, thirteen doubled or more their production in the twenty years from the early 1980s onwards. These include countries where the bulk of output comes from small farms — Burkina Faso, Ghana, Mali, Niger, etc. Countries that have, or had, notable large-farm sectors such as Namibia, South Africa and Zimbabwe are well down the growth ranking. This proves little about scale since other factors are so much more important for agricultural growth, but it does show that to have an agriculture dominated by small farms is no obstacle to growth, and quite rapid growth at that.

On labour productivity, either by level or rate of growth, small farming suffers in comparison to large-scale farming. This is to be expected: small farms tend to apply much more labour per hectare than large units. This creates employment, but the statistics suggest that too often this is poorly rewarded.

Detailed studies and historical reviews show many instances where agricultural booms —periods in which substantial increases in marketed output of both food and cash crops have been seen —have taken place, based on small-scale farming. These can be seen or both export and food crops. An IFPRI survey of technical successes shows that almost all have been applied to good effect by small farmers.

On the other hand, there is no record of generalized success with large farms: on the contrary, there have been some notable failures with large farms — for example, the groundnuts scheme — often associated with reliance on (heavy) machinery unsuited to local soils. There are reasons other than history to explain why, other than for some high value enterprises and for crops that require processing in large-scale plants, large farms are not common in Africa.

For policy these debates are perhaps less important than understanding the conditions under which smallholder development takes place. There is broad understanding that the combination of creating a

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favourable investment climate, spending on public goods, fostering of economic institutions, the presence of demand at the farm gate and conservation of natural resources are necessary. The details of this in particular circumstances can, however, be elusive. But for the purposes of this paper, the record shows that they have been achieved at various times and places: the agenda is not impossible.

Some object to the argument so far, pointing out that history is not necessarily a good guide to the present or future since times change. Africa today is not the same as Asia at the start of the green revolution. Agricultural supply chains are changing with ever more demanding conditions being imposed on would-be suppliers that may marginalize small farms; technical innovations for African conditions may be difficult to generate; environmental degradation and climate change undermine development efforts; HIV/AIDS takes a heavy toll in parts of Eastern and Southern Africa; and the kind of support to farming given by Asian governments thirty-odd years ago is simply unthinkable today. But not all change is negative: agricultural science is better equipped today to produce innovations than before; Asian economic growth, upward pressure on commodity prices present Africa with export opportunities; and biofuels may constitute a major new market for farmers. It is far from clear that African farmers have worse prospects than their Asian counterparts of a generation ago.

An important qualification to the debate is that smallholder development will benefit directly probably no more than the uppermost quartile of small farmers, those with a little more land and resources than their often land-poor neighbours. Surveys show clearly just how unequally land is distributed even within relatively egalitarian villages where there no landlords, only farming households; and the way in which most of the marketed output comes from a minority of small farms.

Does this mean, then, that even agricultural development based on small farms, however successful in producing more, will not reduce poverty and hunger? No, given complementary actions there is every reason to expect multipliers in the rural economy to translate the uneven pattern of smallholder growth into broad-based gains. Measures to encourage the rural non-farm economy, to build links to cities and to provide social protection are more complementary, overlapping and synergistic, than competing.

## INTRODUCTION

Despite urbanisation, Africa is still a predominantly rural continent, with more than 60 percent of 906 million persons living in rural areas in 2005; where most households live in villages and farm, even if they undertake other activities for their livelihoods as well. The bulk of farms are both physically small — of less than two hectares of good arable land, or its equivalent — and operated at the household level using for the most part using family labour.

There are around 33 million small farms — roughly, those with less than two hectares — in Africa, representing 80 percent of all farms, with an average size of 1.6 hectares. There are varying reports of the share of production that comes from small farms, some going as high as 90 percent. Table 1 shows the numbers and shares of farms and area for selected countries. (All data reported in Nagayets 2005.)

**Table 1: Africa, selected countries, small farms**

| | Year | No small farms | Share of farms, % | Share area tilled, % |
|---|---|---|---|---|
| **Ethiopia** | 2001–02 | 9,374,455 | 87 | 60 |
| **Nigeria** | 2000 | 6,252,235 | 74 | |
| **DR Congo** | 1990 | 4,351,000 | 97 | 86 |
| **Tanzania** | 1994-95 | 2,904,241 | 75 | |
| **Egypt** | 1990 | 2,616,991 | 90 | 49 |
| **Uganda** | 1991 | | 73 | 27 |

Source: Nagayets 2005

Debates over the relative efficiency of small and large farms are longstanding (see Hazell et al. 2007). Notwithstanding that the successes of the green revolution in Asia, and above all in China, were achieved largely by smallholders, scepticism about the ability of Africa's small farmers to repeat this experience is widespread. A recent example is an essay by Professor Collier (2008) that argues that to get agriculture in Africa moving, large commercial farms may be a better option than smallholder development.

Why the pessimism over the prospects for African smallholder development? Amongst the reasons mentioned are that Africa's physical geography — soils, climate, hydrology — means that the technical challenge of breeding higher-yielding crop varieties is more daunting and that the possibilities for irrigation are less; that lower world food prices — as seen before the 2007-2008 price spike — made food crop intensification uneconomic; and that governments were unprepared or unable to contemplate providing the extensive state support to kick-start a green revolution in the way that Asian governments had in the 1960s and 1970s.

Furthermore, the of disappointing record of African agricultural development — in many, but not all, countries — over the last 30 or more years not surprisingly invited doubts about the ability of the predominantly smallholder structure of farming across the continent to deliver agricultural development. This essay will argue that the disappointments, although real, are far from universal and that a more detailed examination of the record of African farming show more success than is commonly portrayed.

The paper is made up by the following sections. First, the general debate over the relative merits of small and large farms is set out, looking particularly at the relative efficiency of small and large farms. Following this the empirical record of small and large farms in Africa, such as it is, is reviewed. Third, the conditions under which smallholder development is possible are considered. Qualifications to the main argument are presented in the fourth section, before concluding.

The title of this paper suggests that it will deal with the relation between agricultural development, poverty and food security. That will be attempted only to a limited extent: the main focus here is on the question of whether smallholder development can deliver agricultural growth. Whether such growth, and its pattern, reduces poverty and improves food security is a much wider question; one that will only be touched upon here. This reticence arises mainly from the need to devote space first and foremost to addressing the debate over the feasibility of smallholder development in Africa since this is the main point in contention. Relatively few observers doubt that agricultural development is a necessary, if not sufficient, condition for poverty reduction and food security in Africa: and certainly not after the shock of the 2007-2008 price spike that undermined the argument that food security could readily be achieved through food imports. (Indeed, if anything, mainstream thinking about Africa agriculture — as represented by the African Union's Comprehensive Africa Agriculture Development Programme [CAADP] and the donors and private foundations that support this initiative — is only too convinced that this is the case.) Moreover, the case for agricultural development as being an effective way for low income and largely agrarian countries — as applies across most of Africa — to reduce poverty has been made cogently in the 2008 World Development Report (World Bank 2007).

This is to not to argue that the links from agricultural development to poverty reduction and better nutrition are automatic: they are not. But to widen the discussion to consider these fully would make this a far longer paper than is appropriate. This issue will be revisited briefly in the conclusions.

## SMALL AND LARGE FARMS: RELATIVE EFFICIENCY

Surveys of farms of different sizes in developing countries frequently show small farms producing more per hectare than large farms, with an inverse relationship between farm size and production per unit of land (Cornia 1985, Eastwood & Lipton 2004) — see Figures in Annex A.[1] The explanation usually put forward is that there are few economies of scale in farming, and indeed that there may be diseconomies of scale once

[1] The evidence for the inverse relationship is not undisputed. There are difficulties with definitions of farm size and with measures of productivity. However where studies have tried to refine definitions of size and productivity by, for example, looking at size in terms of land area per worker and adjusting for land quality, the relationship has often been strengthened (Lipton, 1993).

the farm grows larger than can be managed and operated by household labour. These diseconomies arise from labour use: household labour can be readily available, flexible in time and effort to suit the demands of the farm that can be difficult to predict exactly — for example, planting times, control of pests and diseases, harvesting. Above all, household labour is usually self-supervising and motivated to carry out operations diligently. In contrast, larger farms depending largely on hired labour incur (transactions) costs in recruiting and supervising labour. Hence small farms usually apply more labour per hectare than larger farms and consequently produce more — albeit with lower marginal returns to labour.[2]

Diseconomies of scale in farm production are therefore likely to be stronger when labour is a major input to production, as applies when labour is relatively cheap and capital relatively costly — the case in much of Africa.[3]

Other advantages of small-scale in farming that are mentioned are farmers operating small plots may have considerable detailed knowledge of their soils, topography, drainage, etc. allowing them to work the land appropriately. Small farms may be better able to resist temporary slumps in prices, since household labour may be prepared to accept lower returns to their labour at times when a commercial farmer would simply go bankrupt.

Small farms producing subsistence crops also have advantages in circumstances when obtaining staples from the market may involve significant costs and risks; which is still the case in much of rural Africa.

In transactions off the farm, however, countervailing economies of scale apply in procuring inputs, marketing output, obtaining credit and other financial services, in obtaining information on markets and technical issues, in meeting standards and certifying production, and in transacting with large-scale buyers from processors and supermarket chains with their exacting demands for quality, timeliness and bulk deliveries. Poulton et al. (2005) summarise these as shown in Table 2.

**Table 2: Transaction cost advantages of small and large Farms**

| | Small farms | Large farms |
|---|---|---|
| Unskilled labour supervision, motivation, etc | √ | |
| Local knowledge | √ | |
| Food purchases & risk (subsistence) | √ | |
| Skilled labour | | √ |
| Market knowledge | | √ |
| Technical knowledge | | √ |
| Inputs purchase | | √ |
| Finance & capital | | √ |
| Land | | √ |
| Output markets | | √ |
| Product traceability and quality assurance | | √ |
| Risk management | | √ |

Source: Poulton et al. 2005

In some circumstances high transaction costs for credit can stymie production on very small farms, as Dorward (1999) argues when examining farm survey data for Malawi from the 1980s. In this case, production per hectare rose with size up to two hectares; apparently since those with smaller holdings were

[2] This persists owing to factor market failures, since it would be better if smallholders hired out some of their labour to larger farms, or alternatively if the larger units rented out land to small farmers; either of which would be expected to equalise returns to land and labour.

[3] Indeed, the transaction costs of hired labour seem to be so high that across the world for most lines of agriculture — some poultry, pigs, fruit, vegetables, flowers and fish excluded — farms are typically operated at the household scale, with hired labour used only for peak-season operations.

so starved of cash to buy inputs that they had to work on neighbouring farms in the early part of the crop season to raise funds and so neglected their own holdings.

In sum, when labour costs are important, and when at least part of production is for subsistence, small farms may have significant advantages over larger units. Conversely, once agriculture becomes more intensive in transactions beyond the farm gate, larger farms may have the advantage. It should not be expected that the advantages of scale are immutable: they can be expected to change with development. But for much of rural Africa, with relatively low levels of development, there are thus reasons to expect small farms to be as efficient in land uses, or more so, than larger farms.

## THE RECORD OF AGRICULTURE AT SMALL AND LARGE SCALE IN AFRICA

Evidence, albeit incomplete, imperfect and even indirect, to examine the records of small and large farm performance in Africa can be found at both national and district level.

### Insights from national data

Nationally, there are few if any countries in Africa that record estimates of farm output by farm size. That said, there are countries where small family farms dominate agriculture to the point that national statistics are tantamount to a record of small farm performance. Indeed there are few countries in Africa where large commercial farms, estates and plantations occupy more than a small fraction of the land — South Africa and Namibia being prominent exceptions. Thus, with a few countries excepted, examining the record of agricultural growth across Africa would largely reflect the ability of small farmers to increase production; while looking at labour productivity would indicate the ability of the sector to contribute to incomes, poverty reduction and to food security.

The record of agricultural growth since the early 1960s is not good for Africa as a whole. By 2003/05, the continent as whole was producing just under three times more than it did in 1961/63: less than the rate of population growth, so that per capita production had fallen, albeit marginally.4 But this miserable statistic hides important variations through time and space. Agricultural growth slumped in the 1970s across the continent, but in most regions and countries that was followed by recovery and a marked acceleration of agricultural growth in the early 1980s. Hence the record for 1981/83 to 2003/05 shows a continental increase that almost doubles production, outstripping population growth in that period by 10 percent.

Spatial variations are even more striking, as Figure 1 shows. The continental average is comprised of highly variable performances across regions, with Northern and Western Africa doing far better than the rest of the continent; and in these two cases, the acceleration since the early 1980s is particularly pronounced.[5] In both of these regions, production per capita has been raised by more than 40 percent between 1981/83 and

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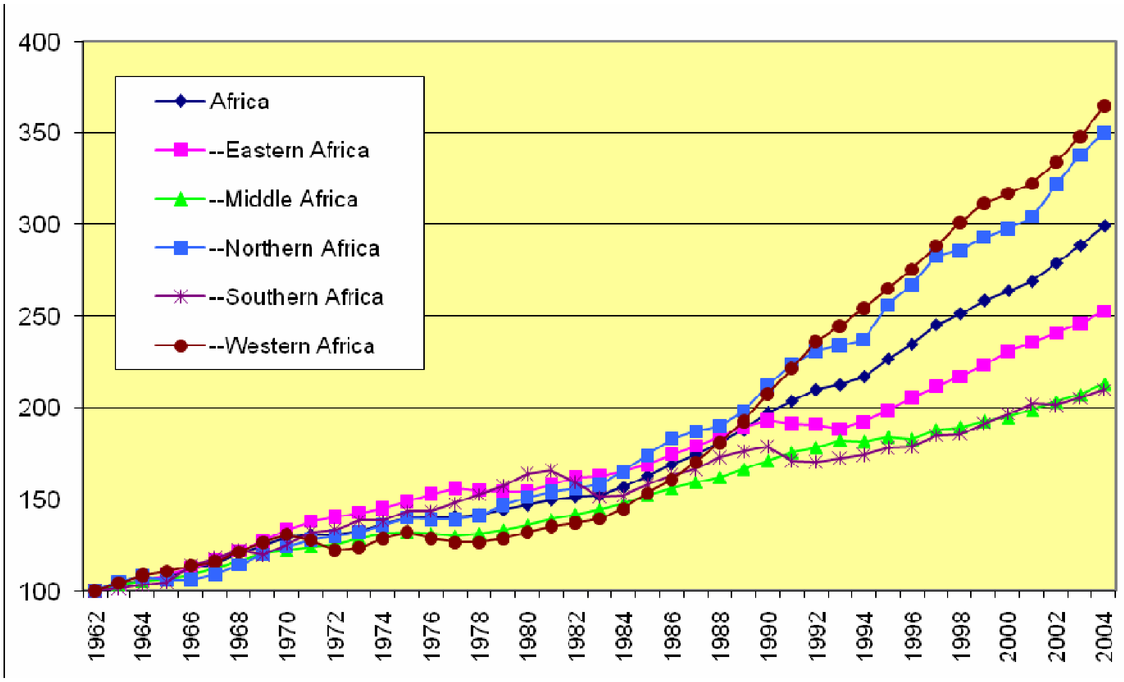
[4] Computed from FAOSTAT data on Gross PIN for agriculture, taking three year moving averages to reduce the effect of annual fluctuations.

[5] Why did agriculture in these two regions see such a pronounced increase in growth from the early 1980s, and why did this not happen in other parts of Africa? If there is a formal study that addresses this question, I do not know it. Of the factors that change in the early 1980s there is a marked reduction in negative protection and that plausibly may have stimulate farming. Western Africa may differ from Eastern and Southern Africa in that there were fewer parastatals organising agriculture that were wound up, privatised or otherwise cut back in the era of structural adjustment; and some of those that did exist, such as the cotton companies of francophone West Africa were left largely intact.

2003/05. The performance of these two regions in raising agricultural output is, surprisingly, the equal of Asia during the green revolution.[6]

**Figure 1: Growth of agricultural production, Africa and its regions, 1961/63 to 2003/05**




Source: FAOSTAT, gross PIN, taking three-year moving averages and basing the index to 1961/63.

A more detailed examination of the record at country level shows considerable variation between countries, including within the regions. Even in regions that have performed poorly, there are some countries that have done quite well in raising agricultural production. Figure 2 shows the agricultural growth performance over the last twenty years for the individual countries of Africa. The range of performance is wide. Thirteen countries more than doubled production, the equivalent of growth at 3.5 percent a year — a rate that comfortably outstrips even rapid population growth. On the other hand, there is a long tail of less impressive and frankly disappointing performances.

Now, what do these statistics suggest about smallholder performance? Simply this: amongst the higher performing countries are several where the bulk of output comes from small farms — Ghana, Burkina Faso, Niger, Mali, etc. There is another observation: those countries that have, or have had, notable large-farm sectors — Namibia, South Africa, Zimbabwe — are well down the growth ranking; and others with smaller but significant large farm sectors such as Kenya and Zambia are not amongst the fastest growing agricultures.

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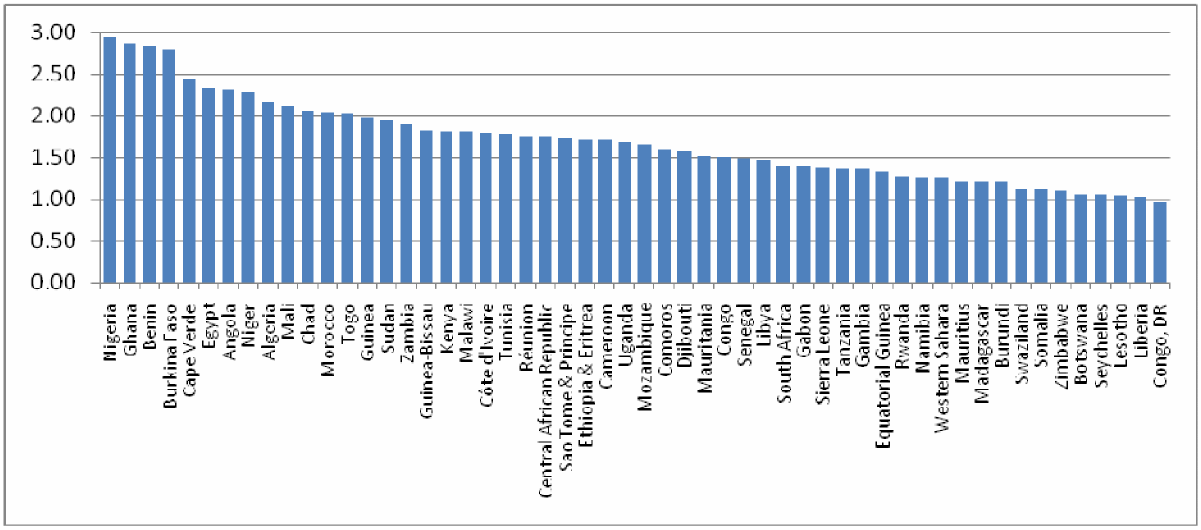
[6] The comparison is this: the increase in value of agricultural output for Northern and Western Africa between 1981/83 and 2001/03; set against that for Eastern, Southern and South-Eastern Asia for 1971/73 to 1991/93, the earlier period reflecting that the green revolution began in Asia in the late 1960s and early 1970s. The multiple in (constant) values of production are as follows:

| | 1971/73 to 1991/93 | 1981/83 to 2001/03 |
|---|---|---|
| Northern Africa | | 2.05 |
| Western Africa | | 2.43 |
| Eastern Asia | 2.12 | |
| Southern Asia | 1.90 | |
| South Eastern Asia | 2.09 | |

**Figure 2: Growth of agricultural output in Africa, 1983/85 to 2003/05**




Source: FAOSTAT data, Gross agricultural PIN, three-year moving averages. Ethiopia and Eritrea combined to allow record to extend before 1991.

Of course, scale of farming is far from being the main factor affecting growth; so this is hardly strong proof of the efficacy of small farms in Africa. Turned around, however, the argument is more compelling: those who believe that small farms cannot be the basis for a rapidly growing agriculture have to explain why countries such as Ghana with its many small family farms has seen growth over the last twenty or so years that is the equal of that seen under the much-vaunted Asian green revolutions. Perhaps Ghana's agriculture would have grown even more quickly had the units been larger, but in the absence of evidence from a country where farming is largely carried out on large scale doing better than Ghana, that would be hard to argue.[7]

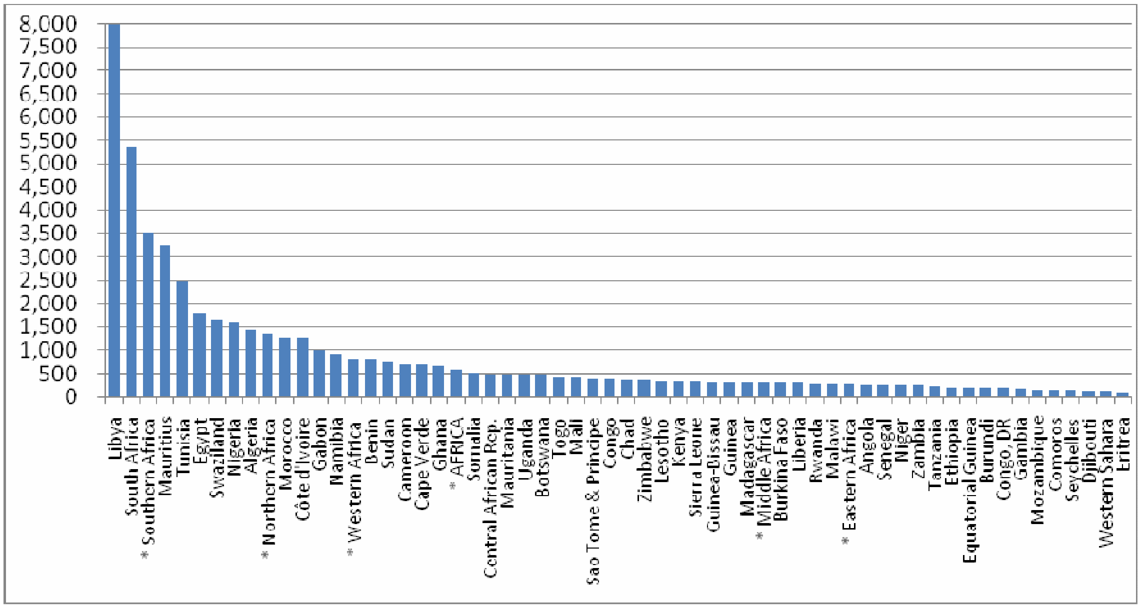
What do the national statistics suggest about ***labour productivity***? Figure 3 shows statistics for the level of labour productivity in Africa. Labour productivity is low, at US$580 per person employed overall, but with marked differences across countries. Only seven countries achieve an average higher than US$1 000 per worker. Countries with significant large farm sectors are prominent: South Africa, Mauritius and Swaziland. The distribution of productivity has a long tail of very low indicators: almost half the countries have estimated average productivity of under US$350.[8]

Growth of labour productivity since the early 1960s is equally variable. Five countries have more than tripled labour productivity in the intervening four decades, and another seven have at least doubled it. At the other end of the distribution, eighteen countries have actually seen labour productivity fall.

[7] Africa does not have many countries where large farms are prominent so perhaps this comparison is unfair. So how does Ghana compare to a country outside of Africa where large farms are important, such as Brazil? Value of production in Brazil rose by 2.15 times between 1983/85 and 2003/05, whereas it rose by 2.87 times for Ghana. All told, nine African countries achieved more growth of production than Brazil in this period.

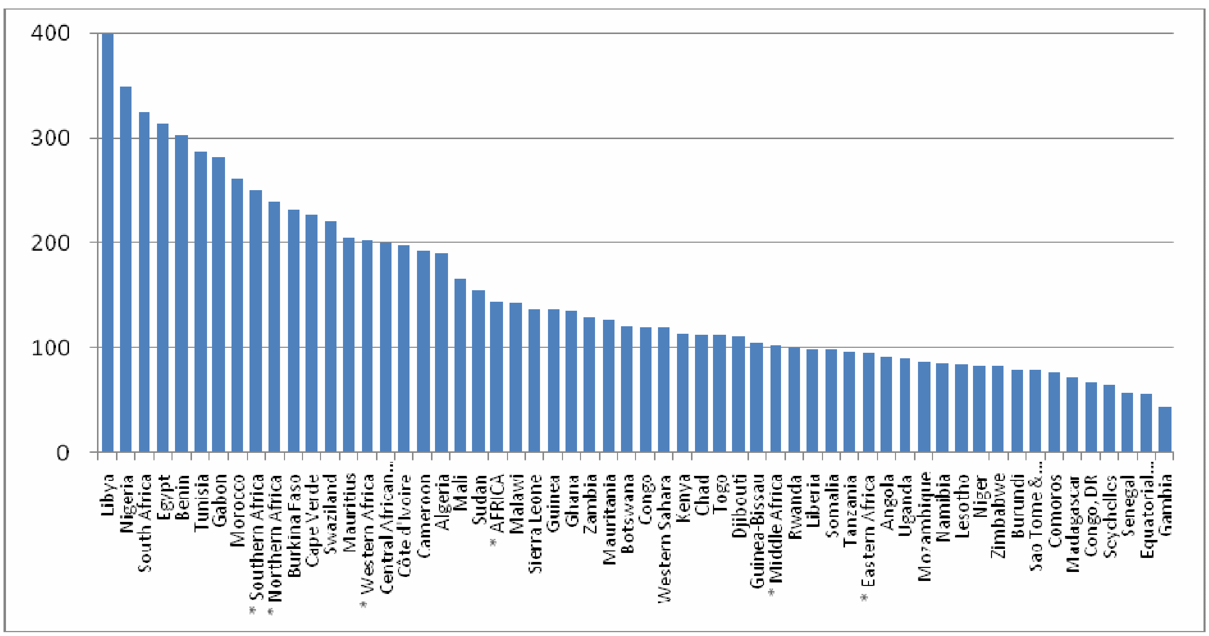
[8] Levels may be low, but the comparison with some Asian countries is instructive. The equivalent figures for China, India and Indonesia are US$725, US$560, and US$670. India's level is thus below the Africa average, and the levels seen for Northern and Western Africa.

**Figure 3: Labour productivity in agriculture, Africa, 2003/05, US$ per worker**




Source: FAOSTAT data for gross agricultural production value divided by the estimated economically active population in agriculture, using three-year moving averages

**Figure 4: Growth of labour productivity in agriculture, Africa, 1961/63 to 2003/05**




Source: as for Figure 3

What may be inferred by small farm labour productivity from this? In many African countries where small farms dominate labour productivity in agriculture is painfully low: insufficient to allow people to escape poverty.[9] Yet there are great variations. Although most of the higher performers are countries with substantial large farm sectors, not all are. Whilst those countries showing the greatest improvements in labour returns include many of the countries with substantial large farm sectors, there are also some where small farms dominate, such as Burkina Faso.

On labour productivity, either by level or rate of growth, small farming suffers in comparison to large-scale farming. This is to be expected: small farms tend to apply much more labour per hectare than large units. This creates employment, but the statistics suggest that too often this is poorly rewarded.

### Smaller-scale studies and other reports

Detailed studies and historical reviews show many instances where agricultural booms - periods in which substantial increases in marketed output of both food and cash crops have been seen - have taken place, based on small-scale farming. During the colonial era, export crop production in West Africa came almost entirely from small farms — groundnuts in Senegal and the Gambia, cocoa in Côte d'Ivoire and Ghana, oil palm in southern Nigeria. In the second half of the twentieth century booms were seen with the small-scale production of export crops such as tea and coffee in Kenya, and in cotton in the francophone countries of the West African guinea savannah and in Zimbabwe (Poulton *et al*. 2004).

There have also been growth spurts based on producing food for domestic markets: hybrid maize in Zimbabwe in the first half of the 1980s (Eicher 1995), in United Republic of Tanzania and Zambia in the 1980s are examples where small farm production has been organised by state agencies. Smaller-scale booms in marketed food crops include rice in the inland delta of the Niger (Diarra et al. 1999), open-pollinated varieties of maize in the middle belt of Nigeria (Smith *et al*. 1993), horticultural exports from Kenya (Minot & Ngigi 2003), and peri-urban production of dairy, fruit and vegetables for the city of Kano (Mortimore 1993).

Not all of these booms have been sustained. On the contrary, they have often been sensitive to prevailing prices, often linked to world market prices, as well as to state support and organization.

IFPRI has documented successes in African agriculture, using an survey of specialists, to identify cases where there had been a 'a significant, durable change in agriculture resulting in an increase in agriculturally derived aggregate income, together with reduced poverty and/or improved environmental quality.' (Haggblade et al. 2003, 10; see also Gabre-Madhin & Haggblade 2001). Most of the experiences captured concern small farmers and herders benefitting from technical advances. These include hybrid maize varieties in Zimbabwe, Kenya and open-pollinated maize in West Africa; use of improved bananas in East Africa; horticulture and fruit produced by smallholders on contract in Kenya; cassava resistant to pests and diseases associated with large increases in cassava production in West Africa, and in parts of south-eastern Africa; cotton in West Africa; and smallholder dairying in Kenya.

These accounts of success contain two strong messages for this paper. One is that almost all the technical advances described have been applied by small farmers to good effect: in no case have the innovations been adopted by larger-scale farms solely or disproportionately,[10] nor is there any suggestion in these accounts that measures to consolidate holdings might be critical to success.

The other is that some of the successes were not sustained, the clearest case being that of hybrid maize in Southern and Eastern Africa where use has stagnated and declined as support in the form of subsidies to inputs, transport and credit have been reduced or withdrawn.

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[9] Assuming that each worker in farming has to support one dependant child or old person, then to escape dollar-a-day poverty average production per worker would need to reach US$730 at very least, given that these are gross estimates with no allowance for any cash costs of farming. The unknown here is what proportion of those counted in the agricultural labour force work full time, and how many have other activities that generate income.

[10] The exception may the case of hybrid maize in Zimbabwe that initially was used mainly by the large-scale commercial farms. But this imbalance was redressed in large degree in the 1980s when the government through the GMB made it possible for smallholders in the communal areas to use the seeds.

The case made is that small farms, under certain conditions, can increase their production significantly. But that does not mean that larger-scale farms might not be even more effective in increasing output, improving efficiency and generally contributing to development. So what of experiences with large farms in Africa? Analysis of ***large farm experiences*** is, however, relatively scant.

Historically there have been several instances when great faith has been placed in the potential of large farms, using the latest technology, to stimulate agriculture. One of the best known, and oldest, of these was the Groundnuts Scheme. Planned in 1947, it was to operate in Tanganyika, Kenya, Northern Rhodesia on 1.3 million hectares to produce vegetable oil for export back to the United Kingdom. By 1949 costs had risen from £26 million to £36 million, less than 100,000 hectares were cleared, fewer nuts had been harvested than expected, and the scheme was abandoned. The scheme relied on machinery that was difficult to get to the sites, where it suffered breakdowns that were difficult to repair in the bush. Subsequent attempts to use untried prototype machinery failed for lack of testing. In any case, the soils and conditions were unsuited to large-scale machine farming. (Johnson & Ruttan 1994).

In 1951 in Ghana, then the Gold Coast, the state set up a company to farm 12,000 hectares at Gonja in the northern savannah using machinery. This soon failed, with only a small part of the area cultivated as the machinery could not be maintained, soils were compacted, and the topsoil eroded by the machines. Subsequent efforts in the late 1950s and 1960s to farm in the savannah on a large scale also failed (Eicher & Baker 1982, Frimpong-Ansah 1991).

In 1971 Bud Antle, a California-based multinational, began to farm vegetables for air export from Senegal using two different modalities: a plantation, and contracting from local small farmers. The plantation, some 450 hectares large, was located only 38 kilometres from Dakar and used drip irrigation to produce melons, green beans, peppers and tomatoes. But the scheme ran into difficulties: soils were easily eroded by the large machines used, the machinery was costly to maintain, and prices in European markets were not always remunerative. By 1976 the operations were losing money and the state bought into the scheme, nationalising it. This lasted until 1979 when continuing technical problems and financial loses led to the operation being closed down (Chasm 1983, Macintosh 1989).

In these cases technical ignorance is prominent, outsiders assuming that techniques deployed to good effect elsewhere will work in rural Africa. The ravages of heavy machinery on fragile soils and the difficulties of operating and maintaining machinery, with its demand for all-too-scarce skilled drivers and mechanics, have led to reduced yields and heavy operating costs.

These, however, are not the only problems that large farms encounter. Being formal companies they are often expected to comply with regulations that are rarely if ever applied to small farms: payment of legal minimum wages, provision of housing, education and health care to hired workers and their families, and taxation. In addition, being highly visible formal enterprises in rural areas they can be targets for informal payments to officials unusually anxious to check that the company is complying with rules, as well as for thieves looking to pilfer stores. All told, operating a large farm can be a costly business, running up spending that no small farm has to meet (Paul Wagstaff, 2009, contribution to email conference).

This is not to argue that all large farms fail technically or operate at high cost in Africa. There are examples of large-scale farming that works well. The point is rather that large-scale farming is not always technically or financially the better option. While this may seem obvious, the tendency for unjustified optimism that big means better in farming remains unabated, even in countries with a record of failures. Ghana under President Kufuor is a case in point. Notwithstanding the rapid growth of agricultural production seen in the country since the early 1980s, achieved almost entirely by small farmers, and the well-known failures of large farms promoted by the late colonial and Nkrumah governments, ministers were seduced by the vision of modern, large-scale farms on the plains of Brong-Ahafo producing a rapid spurt to agricultural growth. Meanwhile across Africa since early 2008 all kinds of schemes have been announced by foreign companies to acquire land and farm on a large-scale for export back to the Gulf and East Asia to counter rising world commodity prices. Once again, it seems, outsiders discount the challenges of farming in Africa and assume that given technology and scale all will be well. History suggests otherwise.[11]

It is thus not surprising that large-scale farming in Africa, outside of the settler economies of Southern Africa, is largely confined to high-value and specialist ventures such as fruit, vegetables, flowers, intensive pigs and poultry; and where local processing plants, often fairly large-scale, are necessary for crops such as sisal, sugar, tea, rubber and coffee. These are cases where large capital investments are necessary, or where industrial organisation of production generates physical productivity that cannot be achieved on small units.

## CONDITIONS FOR SMALLHOLDER DEVELOPMENT

The record shows that smallholder development has delivered agricultural growth in various places and at various times, and that growth is not always sustained. What, then, are the conditions under which smallholder development is possible? These are well-known. They include:

1. A favourable investment climate for farming. Critical here is a level playing field , that is that farmers can buy inputs, access finance and sell their produce on something like neutral terms in which they are not exorbitantly taxed by domestic policy, albeit implicitly, or having to compete with dumped food imports, or exporting to markets where prices have been depressed by the policies of OECD countries. A comparison of agricultural growth in Africa between the 1970s and 1980s, the former decade one of heavy negative protection of many farm sectors that eased during the 1980s, shows just how important negative protection can be.[12] It also implies that farmers can trade with relatively low transaction costs and are not exploited by agencies with monopoly power.
2. Investment in public goods that support agriculture, most notably agricultural research and extension, rural roads, education, health care, and , in some cases, irrigation and power supplies. It is probably not so much the amount that is spent by governments on agriculture, so much as on what is funded that counts: returns to spending on public goods seem to be high, while those to private goods may be lower (Fan & Rao 2003).
3. Developing economic institutions to allocate and protect property rights, to facilitate trading, to reduce risk and to allow collective action. This is a challenging agenda: in the absence of effective institutions market failures arise that ultimately prevent investment and deter innovation and initiative.

These first three elements might be seen as the public agenda.[13] In addition to which there is:

4. The existence of demand that is transmitted effectively to the farm gate. Reviewing studies of agricultural development at village and district level in the 1970s and 1980s, the single main factor that stimulated spurts in agricultural growth appeared to be demand felt at the farm gate (Wiggins 1995, 2000). That demand arose variously from urban growth domestically, from linking farmers to

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[11] It is a working assumption that successful large-scale farms in the Southern Africa economies were not an overnight success, and that the settlers leaned how to farm Africa through trial and error, adapting their imported techniques (and indeed some crops and animals) to local conditions.

[12] The argument was made powerfully by Krueger, Schiff & Valdés (1991). Most of the negative protection seen in the 1970s was indirect: the result of overvalued exchange rates and protection of domestic manufacturing.

[13] Poulton et al. 2006 in reviewing commercial farming in Africa summarise these conditions as:

> The enabling environment consists of macro-economic stability — exchange rates, inflation; functioning basic infrastructure, effective commercial banking, and an investment climate with secure property rights and predictable and low taxation. Not only this, but governments need to reinvest their tax take — in better physical infrastructure, in research.

these markets by better roads; or from parastatals offering farmers in remote areas pan-territorial prices that discounted the cost of transport.

To these may be added a fifth condition:

5. That farmers conserve their land, water and other natural resources so that physical production can be sustained.

It easy enough to specify these conditions, but the record of disappointments in African agriculture over the last thirty or more years shows that meeting them is no simple exercise. Problems arise in low-income countries where public resources are limited and the range of apparently necessary investments is wide, exceeding any imaginable budget. In such cases, there are difficult strategic decisions to be made about the combination and sequences of policy and investments to follow; for which there is relatively little guidance in the literature. But matters have sometimes been made worse by misguided policy and poor governance.[14]

Much of the literature on African agricultural development explores these conditions: how they apply in different circumstances - including the extent to which farmers are close or remote from the market, the quality and quantity of natural resources they can use, and population density (see, for example, Snrech 1995, Wood et al. 1999); and how they can best be met. This is not the place to revisit these arguments: for this paper it is sufficient to note that smallholder development requires certain conditions, and that - demanding as they may be - history suggests that they have been sufficiently met at various times and places for vigorous agricultural growth to occur.

## A FREQUENT OBJECTION AND A CLARIFICATION

A frequent objection to arguments for small farm development in Africa based on history is that times have changed, and what might once have been possible no longer is. Ellis (2005) argues that

> 'Sub-Saharan Africa in the early 21st century is not Asia in the 1970s, and this needs to be well understood since otherwise invidious and unhelpful comparisons are made concerning the ability of SSA to replicate the Asian experience.' (1)

Amongst the factors seen as changing the possibilities for African smallholder development, especially in comparison to the conditions seen in Asia in the 1960s and 1970s, are:

- Changes in supply chains with increasing organization of agricultural and food marketing by supermarket chains, resulting in demand for bulk deliveries of standardized produce with stringent quality criteria, sometimes with certification of production conditions to boot, to strict timetables. These could marginalize small farmers who, it is feared, cannot produce to such standards, giving a decisive advantage to large units, and leaving small farmers with access only to markets where lower prices apply to second-best produce;
- The difficulties of producing technical innovations for the diverse, rainfed ecologies of much of Africa, in contrast to producing improved seeds for the irrigated lands of Asia. To this may be added the increasingly private nature of agricultural research with correspondingly fewer incentives to produce innovations for small, and poor, farmers;
- The challenges of environmental degradation, water scarcity - and an associated paucity of opportunities to irrigate, and climate change. Some see Africa as suffering badly from soil erosion and degradation;
- That the kind of support to farmers seen in Asia in the past, particularly subsidies on fertilizer, irrigation water and rural power, is unthinkable today;

[14] The extent to which the problems of African agriculture can be put down to lack of resources for investment, or to poor governance, is highly controversial, with strong views held by either side.

- The impact of HIV/AIDS on farming that in parts of Southern and Eastern Africa deprives affected households of labour and capital; and, until last year,
- The long-term decline in agricultural commodity prices that reduced the profitability of farming - and, by making imports ever cheaper, reduced the value of producing food domestically and thereby made arguments for self-sufficiency less compelling.

Against these changes can be set others that may imply equally good or better prospects for African agriculture and its smallholders, thus:

- Technically, advances in biotechnology may make it easier to produce innovations suited to African conditions. During the last two decades the spread of improved cassava and the generation of the new rice for Africa strains (NERICA) are two promising developments with widespread applicability for farmers;
- Rapid economic growth in Asia means that some countries are now importing some commodities, such as soy beans and palm oil, on a very large scale. So far that demand has been met by production from South America and South-Eastern Asia, but Africa could be a supplier as well.[15] The recent price shock has awakened interest in Africa as an exporter of food to Asia and the Near East. For those parts of Africa with underused land, as seen in the guinea savannah, and especially those along the Indian Ocean seaboard, there is the potential to produce and export, thereby relieving the constraint of limited local demand for additional production; and,
- The surge in production of biofuels seen when oil prices started to rise from 2006 onwards makes clear the potential for producing biofuels in Africa, and above in landlocked countries with spare land, to replace increasingly cost fuel imports. Across Africa studies are being carried out to assess this potential. If the economics are really as good as preliminary assessments suggest, then a major new opportunity exists for farmers.

Weighing the balance of these different factors is more a matter of judgment than calculation. Those who argue that changed circumstances make former options inapplicable, need to bear in mind how quickly some circumstances can change, as seen most notably with concerns over the apparently inexorable decline of commodity prices that have evaporated in the last eighteen months.

But perhaps more important is that policy-makers need to be considering how to minimise the disadvantages and maximising the pluses. How much do the above factors affect smallholders as opposed to large farms? The clearest case is that of changing supply chains: if smallholder development is to achieve its potential, then finding effective ways to minimise transaction costs and allow small farmers to supply the emerging chains will be critical. Similarly, market failures in access to finance and inputs are likely to be more severe for small than large farms. It is not surprising, then, that some of the most energetic debates in the last few years in Africa have turned on how to ensure that small farmers can obtain fertilizer.

An important clarification in the debate concerns the nature of small farms. To some extent debates are obscured by unstated assumptions about the small farms that are in contention: is the debate about farms with the equivalent of two or three hectares of reasonable arable land, or is it about the land hungry who have access to plots of one hectare or less?

Recent surveys in Eastern and Southern Africa (Jayne et al. 2005), see Figure 5, show that generally only the top quarter of farmers have two or more hectares: often 50 percent or more have less than one hectare, and the bottom quarter have half a hectare or less. Concern over the prospects for very small, perhaps marginal, farms are thus highly pertinent.

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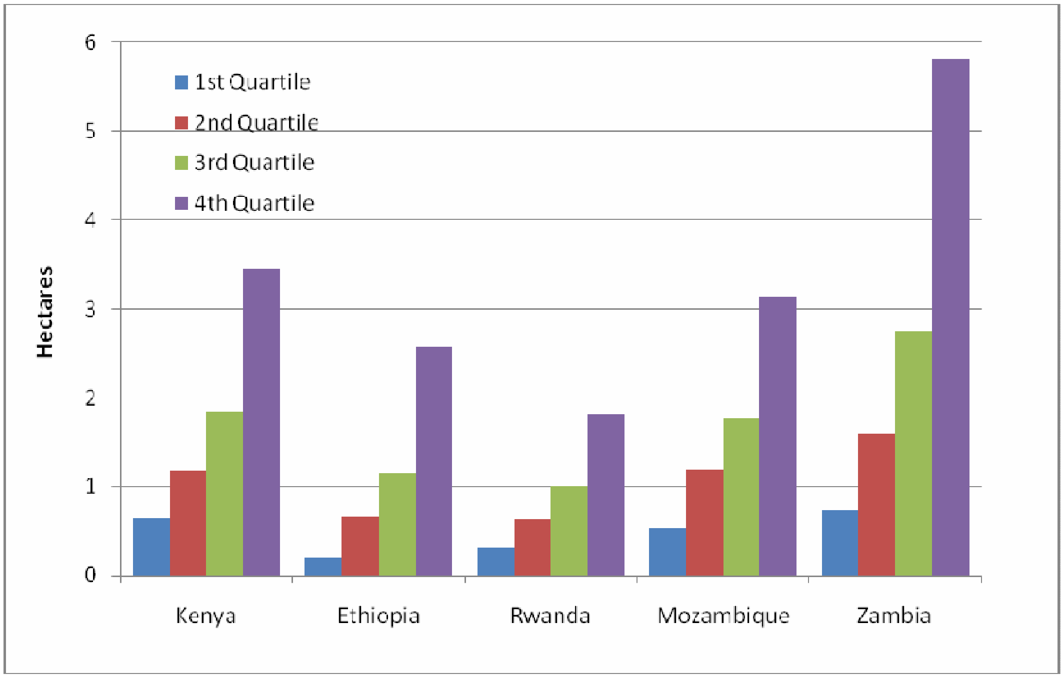
[15] The planned acquisition of land in Madagascar by Republic of Korea's Daewoo was partly intended to produce palm oil.

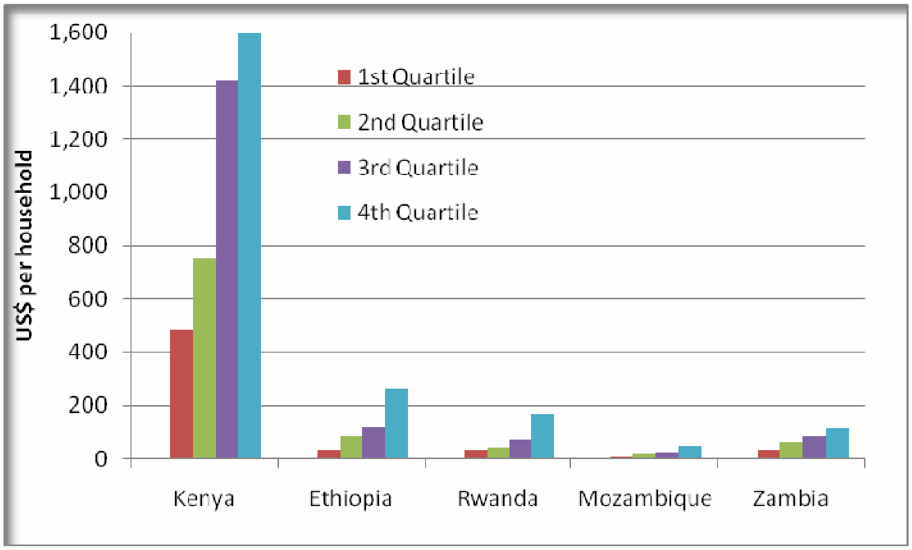
**Figure 5: Land distribution amongst small farmers in Eastern & Southern Africa, late 1990s. Average land sizes for farmers by quartiles**




Source: derived from Jayne et al. 2005 reporting the results of surveys of small farmer communities carried out in the 1990s

Moreover, surveys in Africa that report the size of farms marketing produce often show that the bulk of marketed output from small farms comes from those that are towards the upper part of the range. For the same set of surveys, the value of marketed output by landholding quartile appears in Figure 6. Sales of grain in these five countries come from 20–50 percent of the smallholders in a normal year, and even then there is marked disparity between a very small group of relatively large and well-equipped smallholder farmers with 4 to 20 hectares of land, usually in the most favourable agro-ecological areas (about 1– 4 percent of the total rural farm population), accounting for 50 percent of the marketed output from smallholdings who sell between 5 and 50 tons of maize per farm in a given year, on the one hand; and a much larger group of smallholder farms (20–30 percent of the farm population) selling much smaller quantities of grain, between 0.1 and 5 tons per farm, on the other. This leaves 50–70 percent of rural households who are buyers of staple grains. (Jayne et al. 2005) Similarly, Scoones et. al. (1996) write that in Chivi, southern Zimbabwe, an area of small farms on communal areas, fully 75 percent of marketed farm output in the early 1990s came from just 25 percent of farms.

**Figure 6: Value of marketed output, US$/household, amongst small farmers in Eastern & Southern Africa, late 1990s, by landholding quartile**




Source: derived from Jayne et al. 2005 reporting the results of surveys of small farmer communities carried out in the 1990s

It is clear that there is considerable differentiation amongst small farms. Those who advocate the potential of small farm development need to recognise that most of the increased production, and hence increased earnings will accrue to only a minority of small farms. The implications of this will be taken up in the next, concluding section.

## CONCLUSIONS

This paper argues that small farmers in Africa have a record of agricultural growth that suggests that, yes, more farm output can be achieved largely through smallholder development - just as has been the case for the Asian green revolutions. The recent history of African agricultural development is highly uneven across countries, and very probably equally so between regions within them. The disappointments that have led some to pessimistic assessments of the continent's prospects are real. But the same unevenness includes successes that are not always recognised. The implication seems clear: there are no specifically African disadvantages. If, for example, Burkina Faso, a small, landlocked country in the Sahel with at best modest natural resources, can raise its grain output - coming very largely from small farms - from the early 1960s by virtually the same margin as Vietnamese rice output,[16] then surely most other countries in Africa can similarly develop their agriculture.

Even if in general terms the elements for success are well known, since the detail is elusive, it is not necessarily straightforward to stimulate smallholder agricultural development. The challenges can be quite stiff in some cases. This, however, should not cause the effort to be abandoned in favour of untested alternatives, such as trying to create and support large farms, that face many if not all of the same issues. Most of the agenda for small farm development is common to any form of agricultural development, and some of it applies to all economic development; so special and unusual resources are not required. On the contrary, history shows examples where modest investments of public spending in a reasonably favourable

[16] Against a base of 1961/63, the index for the five-year average 2001/05 shows 367 for Vietnamese rice, and 369 for Burkina Faso grains. Over these four decades Vietnam registers one of strongest increases in grain production in Asia with Indonesia being amongst one of the few major nations outperforming it.

[In 1961 Burkina produced 716k tonnes of grains: by 2004 the figure was estimated at 2.9M tonnes, according to FAOSTAT.]

policy context leads to strong response, in effort, innovation and investment by small farmers themselves - and those they work with in supply chains, such as traders.

A belief in the possibilities of agricultural development based on small farms, however, does not necessarily or probably mean that all small farmers will participate in growth to the same degree. On the contrary, it is likely that it will be minority of small farms that see the bulk of added production and sales.

This brings the argument back to the original question posed: that of smallholder agricultural development and the ultimate goals of poverty reduction and food security. If much of the growth takes place on relatively few (small) farms, does this mean limited impacts on poverty? The answer is no, not necessarily. Given the right kind of complementary actions, benefits can be spread more widely.

Cross-country econometrics show strong associations between agricultural development and poverty reduction, an association that tends to be stronger for Africa than elsewhere. For example, Irz et al. (2001) estimate that for every 10 percent increase in farm yields, there has been a 7 percent reduction in poverty in Africa, more than the 5 percent reduction estimated for Asia. Growth in manufacturing and services has no such effect. The 2008 World Development Report compiles the evidence as follows:

> Among 42 developing countries over 1981–2003, 1 percent GDP growth originating in agriculture increased the expenditures of the three poorest deciles at least 2.5 times as much as growth originating in the rest of the economy ….
>
> Similarly, Bravo-Ortega and Lederman (2005) find that an increase in overall GDP coming from agricultural labor productivity is on average 2.9 times more effective in raising the incomes of the poorest quintile in developing countries … than an equivalent increase in GDP coming from non-agricultural labor productivity ...
>
> Using cross-country regressions per region and looking at $2-a-day poverty, Hasan and Quibriam (2004) find larger effects from agricultural growth on poverty reduction in Sub-Saharan Africa and South Asia, but larger poverty-reducing effects of growth originating in other sectors in East Asia and Latin America.
>
> [World Bank 2007, Box 1.2]

It is not hard intuitively to explain why smallholder development, that probably sees immediate benefits to a few small farmers, has such an effect on poverty. Farming in Africa is generally intensive in labour, and especially so on small farms. When small farmers expand production they invariably have to hire in more labour and thus demand for rural labour rises to the benefit of land-poor neighbours who need additional work off their small plots. It is plausible, too, that supply of labour falls as some of the small farmers, with enhanced farm incomes, withdraw from occasional labouring. Then there are links from farming to the rural non-farm economy. More output means more jobs in supplying inputs, processing, and transport. Even more important, small farmers tend to spend much of their additional income locally on construction, services, and local manufactures such as furniture; so that links through consumption can be strong.

Formal modelling of such rural linkages in Africa have produced estimates of 1.35 for rural Sierra Leone in 1974–75 (Haggblade, Hammer & Hazell 1991) to estimates ranging from 1.31 to an extraordinary 4.62 for Burkina, Niger, Senegal and Zambia in the 1980s (Delgado et al. 1994, Delgado, Hopkins & Kelly 1994) - the very high estimates being explained as the result of isolation in rural Africa which means that any exogenous increase in farm earnings will be spent disproportionately on locally-produced goods and services.[17]

These effects are likely to be strengthened if there are complementary efforts to support the livelihoods of those with very small farms for whom a more commercialised small farming will not be a route out of poverty. Dorward (2009) presents a simple scheme to link such differences to policy implications, consisting of three options:

- ***Stepping up***: intensify farming through improving transport, facilitating access to inputs and credit, investing in technology and through farmer organisation

[17] The multipliers for rural Africa reported by Delgado and colleagues have been criticised by de Janvry (1994) as being based on unlikely assumptions about the perfect elasticity of supply of non-tradables.

- ***Stepping out*** into the non-farm economy by more education and skills, better health care, and providing potential migrants with information on opportunities, conferring on them transferable rights as citizens and facilitating remittances; and,

- ***Hanging in,*** providing social protection for those who have few assets and options, investing in technology for food staples to allow them to make best use of their small plots, and making sure that the next generation get a better start than their parents through primary health care, infant nutrition, and schooling.

The beauty of this formulation is that it sets several current debates in context. Yes, conventional agricultural development is needed for some farmers; but not for all: the technology of food staples for the very poor and near-landless may need to be different to that provided to small farmers with more potential, stressing innovations that save labour and use external inputs sparingly. The rural non-farm economy can be seen as complementary to agricultural development, rather than an alternative.[18] Social protection is an important way to deal with chronic poverty, but not the only measure. Finally, rural development matters, but it is not exclusive of urban development: rural areas and urban centres are linked so that demand from urban areas for agricultural produce, supply of inputs for farmers from industries based in cities, and opportunities for households to diversify by migrating to urban areas are all potential ways forward.

Finally, will smallholder development deliver food security? It will help: more food availability is likely to tend to push down food prices, while increased incomes for the poor are likely to mean greater access to food. But this will not be sufficient. A substantial part of the problem of child malnutrition in areas such as West Africa comes from disease, not food supply. For better nutrition, the continent needs to do as much to ensure access to clean water, sanitation, and primary health measures, as to grow more food - see Wiggins & Keats (2009) for a review.

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[18] The debate that poses the non-farm rural to the agricultural economy is somewhat sterile: most of the spending and policy that supports agriculture — rural roads, education, health care, power supplies — also supports the rural non-farm economy. The main element of trade-off concerns spending on agricultural research, and here the good news is that a small investment goes a very long way, so it is not necessary to commit major parts of the public budget to support farming alone.

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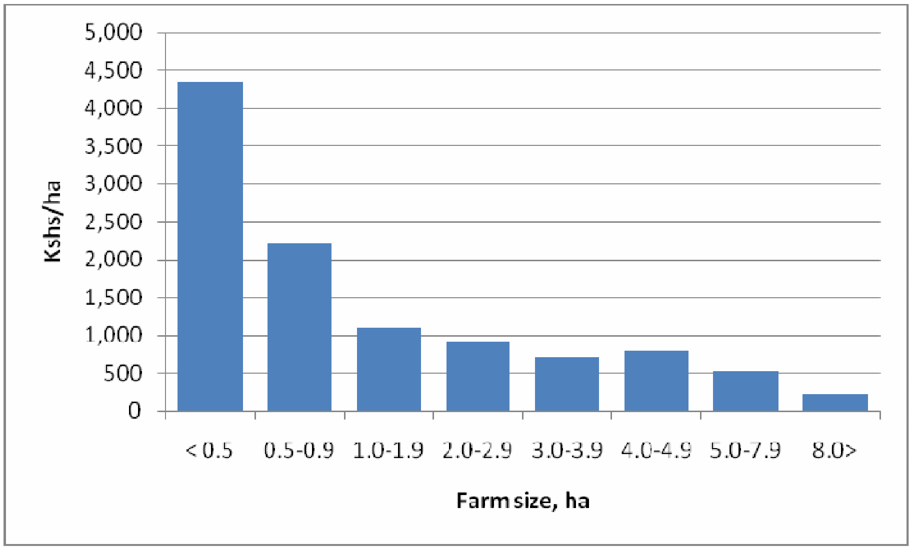
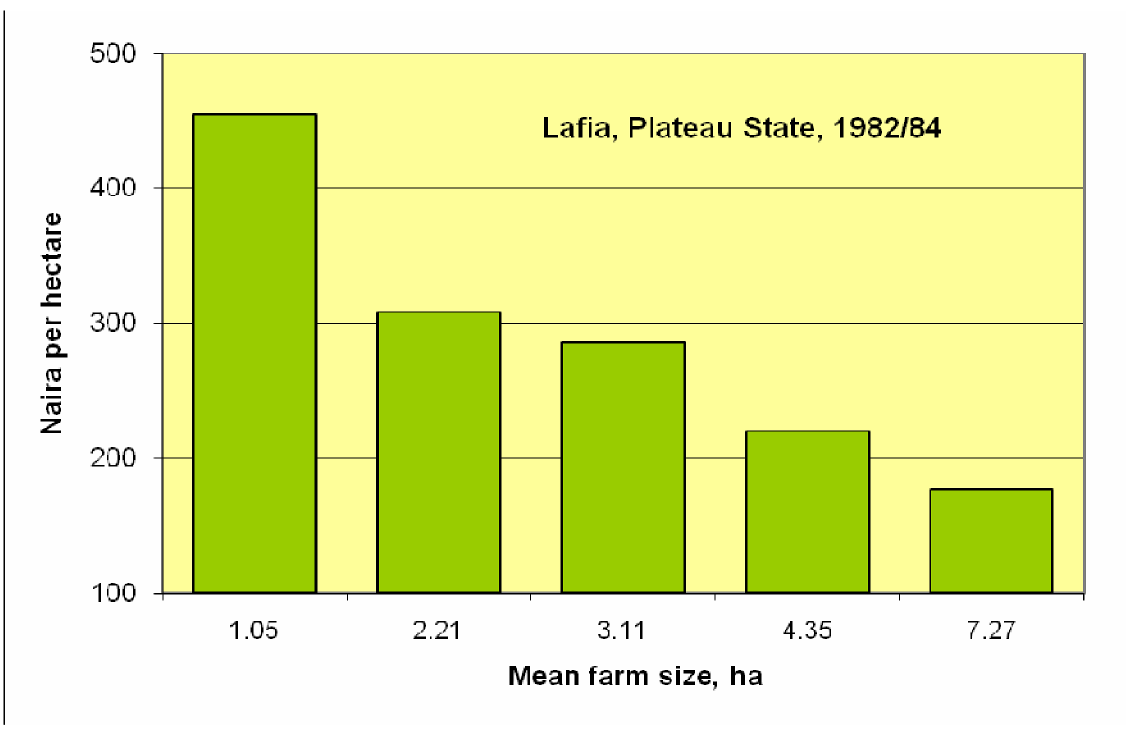
## ANNEX A: EVIDENCE OF THE INVERSE RATIO OF FARM SIZE TO PRODUCTION PER HECTARE IN AFRICA

### A1: Kenya: smallholder areas, 1974/75: value of output by farm size




Sources: Dorling 1979, Tidrick 1979, quoted in Hunt 1984 (Tables 9.4 & 9.5)

### A2: Lafia, Plateau State, Nigeria, 1982/84




Source: APMEPU, in Eyoh 1990, 1992

# AFRICAN AGRICULTURE IN 50 YEARS:

## SMALLHOLDERS IN A RAPIDLY CHANGING WORLD?

**Paul Collier and Stefan Dercon***

## ABSTRACT

For economic development to succeed in Africa in the next 50 years, African agriculture will have to change beyond recognition. Production will have to have increased massively, but also labour productivity, requiring a vast reduction in the proportion of the population engaged in agriculture and a large move out of rural areas. Climate change is likely to require an acceleration of this process, with commensurate faster and further migration of large populations. In this paper, we ask how this can be squared with a continuing commitment to smallholder agriculture as the main route for growth in African agriculture and for poverty reduction. We question the evidence base for an exclusive focus on smallholders, and argue for a much more open-minded approach to different modes of production. Smallholders are heterogeneous and there is scope for large scale farmers as commercial enterprises, often in interaction with smaller scale farmers using institutional frameworks that encourage vertical integration and scale economies in processing and marketing. Furthermore, we question the case for smallholders as engines for growth and poverty reduction. The evidence is far more mixed than the exclusive emphasis upon the smallholder approach would lead us to believe. Indeed, much of the focus on smallholders may actually hinder large scale poverty reduction. Fast labour productivity growth is what is needed for large scale productivity reduction but smallholders and the institutions to support and sustain them are weak agents for labour productivity growth in Africa. The current policy focus ignores one key necessity for labour productivity growth: successful migration out of agriculture and rural areas. In the final part of the paper, we consider the recent African vogue for 'superfarms': the emergence of investments in vast tracks of land of thousands of hectares for food crop agriculture focused on exports, such as to the Middle East. We argue that, while commercialization of African agriculture is desirable, the superfarms are fundamentally geopolitical rather than commercial and are not an appropriate vehicle for encouraging growth in African societies.

## INTRODUCTION

It is instructive to think ahead and ask the following question. If, over the next half-century, Africa were to converge on the performance of much of the rest of the developing world both in growth and in poverty reduction, what would be the defining features of the organisation of its agriculture in 2060? The historical experience of most rich economies and the recent experience of fast growing developing Asian economies suggest that five essential characteristics would be concomitant with success: first, a vast reduction in the number of people engaged in agriculture (as this is a feature of economic transformation); second, a massive increase in the urban population and coastal population (as this is where economic activity will increasingly be located); third, in rural areas, a vast reduction of the size of the population living in areas relatively far away from urban areas and from the coast (as incomes in agriculture can only keep up with other incomes where demand is located or where transport is cheap); fourth, a considerable increase in labour productivity in agriculture (as otherwise poverty will have remained high); and fifth, a considerable increase in overall agricultural production, especially in those countries and areas relatively inaccessible from coastal areas (as

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plentiful and sufficiently cheap food is essential for living standards and growth, and in these non-coastal or less accessible countries and regions, imports will be too expensive to sustain real wages, affecting growth).

The first three are directly linked to migration as part of economic transformation; the fourth is not linked by necessity but nevertheless is typically linked to migration, as throughout the history of development, sustained labour productivity increases have been mainly achieved through the release of labour from the land. For example, between 1500 and 1800 there was such a transformation in England (Allen, 2009), and in recent years the same has occurred much more rapidly in China, where the rural share of the population has decreased from more than 80% to about 55% in the last 20 years, with rapid increases in labour productivity in agriculture (McErlean and Wu, 2003).

Why might Africa differ from this global historical pattern? The key additional factor to take into consideration is prospective climate change, which of course was not a significant factor in the above transitions. Climate change strongly reinforces the need for African agriculture to adapt. If African agriculture is to be successful despite overall deteriorating agro-climatic conditions, new crops or varieties will need to be grown, often using different technologies. Furthermore, the geographical distribution of agricultural activity will have to change.

The five characteristics of success are unlikely to be contentious. Nevertheless, they contrast with the current character of much of African agriculture: a vast and only slowly changing number of poor smallholders contributing most of agricultural output, with low yields, limited commercialization, few signs of rapid productivity growth, and population-land ratios that are not declining. In sum, the current experience is far from being the radical economic transformation which would be appropriate over the next 50 years.

To switch from the slow changing pattern of the past few decades to an agriculture which is rapidly evolving during the next five decades to the entirely different pattern of 2060, a radical improvement in the performance of agriculture is evidently needed. So far, little that we have said should be controversial. The contentious issue is whether the current model favoured by donors and most agricultural economists is likely to achieve such a transformation. Its approach is to stimulate growth in smallholder agriculture by a variety of interventions, from technology to market development (see e.g. the World Bank's World Development Report, 2008).

The rationale for this conventional donor approach is embedded in the standard development model taught in any basic course in agricultural or development economics. It has three principles: first, both growth and poverty reduction will have to start from agriculture; secondly, smallholder agriculture is pretty efficient in what it does and thirdly, it needs improvements in technology as well as the functioning of markets (such as for inputs, credit, and output). Once we unlock this potential, growth in agriculture and from this, growth in the rest of the economy will follow. It justifies the current focus of much thinking on supporting African agriculture: an exclusive focus on smallholders as the key to growth and poverty reduction.

In this paper, we question this model. More specifically, we argue that the perceived wisdom of the likely success of this strategy is based on weaker evidence than is commonly suggested, while both the changing global economic context and climate change suggest that this strategy is unlikely to be successful. In short, without considering more radical strategies, Africa's agricultural growth prospects may be weak. The alternative is not to ditch smallholders and return to the discredited 1950s and 1960s models of mechanized agriculture in the spirit of the Groundnut Scheme. Rather, it is to consider more flexible organisational models in which not all bets are placed on a single unquestioned mode of production. There are striking examples of rapid successful commercialization elsewhere in the world, most notably in the Brazilian Cerrado region or in the Northeast Region in Thailand.[1] The Brazilian success is especially striking as agriculture is taking place in difficult agro-

[1] Both regions started from 'backward' regions in the 1960s to become successful centres of commercial agriculture, run by private commercial farm and trading enterprises. In Brazil, the farming conditions led to large-scale mechanized production of soybean and rice; in the Northeast region of Thailand, cassava and rice dominate, and farms remain of relatively smaller size but with plot consolidation, vast area expansion and some mechanization, they became commercial farm enterprises different from the typical small peasant and family firms dominating Thai agriculture (World Bank, 2008).

climatic conditions similar to parts of Africa, and some Brazilian companies appear keen to invest in farms in Africa.

In the rest of the paper, we first discuss whether the evidence base for an exclusive focus on smallholders is really justified, and argue for a much more open-minded approach to different modes of production. Smallholders are heterogeneous and there is scope for large scale farmers as commercial enterprises, often in interaction with smaller scale farmers using institutional frameworks that encourage vertical integration and scale economies in processing and marketing. In the second section, we return to the case for smallholders as engines for growth and poverty reduction. Again, the evidence is far more mixed than the exclusive emphasis upon the smallholder approach would lead us to believe. Indeed, much of the focus on smallholders may actually hinder large scale poverty reduction. Fast labour productivity growth is what is needed for large scale productivity reduction but smallholders and the institutions to support and sustain them are weak agents for labour productivity growth in Africa. The current policy ignores one key necessity for labour productivity growth: successful migration out of agriculture and rural areas.

In the final part of the paper, we consider the recent African vogue for 'superfarms'. We argue that, while commercialization of African agriculture is desirable, the superfarms are fundamentally geopolitical rather than commercial and are not an appropriate vehicle for African societies.

## 1. IS AN EXCLUSIVE COMMITMENT TO SMALLHOLDERS WARRANTED?

There is plenty of evidence that poor smallholders are quite efficient in what they do. This view of 'poor but efficient' was powerfully promoted by T.W. Schultz, who famously stated that "(t)here are comparatively few inefficiencies in the allocation of factors of production in traditional agriculture" (Schultz, 1964, pp-37-8). In itself, this is not a justification for focusing on smallholders as the agents for growth in agriculture, as other modes of production may be better at shifting the technology frontier. The empirical argument in favour of smallholders over large scale production tends to rely on the 'inverse productivity' relationship, going back to Chayanov (1926), but found to be present across a wide variety of contexts: that yields per hectare are higher on smaller farms. To explain this, standard explanations focus on labour supervision costs making hired labour expensive relative to family labour and reducing land productivity on larger farms (Eswaran and Kotwal, 1986). Other market imperfections such as related to insurance could also deliver these findings (Barrett, 1996).

Against this, there are good theoretical reasons why market imperfections would actually result in scale economies in agriculture (Eastwood et al., 2009). Reasons include lumpy investment (e.g. machinery, oxen) or working capital needs. For example, Eswaran and Kotwal (1986) use the latter to argue that the smallest farms may be less efficient if collateral requirements affect their ability to raise working capital. In several settings, there is evidence that these factors matter (Eastwood et al. 2008). The result is that any empirical regularity regarding the inverse productivity relationship requires that these sources of economies of scale are outweighed by these plausible labour market imperfections.[2]

Descriptive statistics (e.g. showing higher profits per hectare on smaller plots in national farm surveys) are not particularly helpful as agro-climatic and especially soil quality differences should at least be controlled for. There are (only) a handful of reasonably careful studies showing the inverse farm-size/productivity relationship in African settings (including van Zyl et al., 1995 for South Africa; Kimhi, 2003 for Zambia; Barrett, 1996, for Madagascar) but also some showing the reverse (i.e. positive) farm-size/productivity relationship (e.g Kevane 1996 for Sudan; Zaibet and Dunn, 1998, for Tunisia).

[2] Labour market imperfections, related to supervision costs of hired labour and the implied labour (shadow) cost of family labour are key; if small farmers are more efficient because of insurance market failures then finding ways to offer insurance would be efficiency improving, and may reverse the relative advantage of small farms. In general, the policy implication is then not to promote smallholder agriculture but to try to resolve the market failures.

However, does any of this evidence really cast a clear judgement on whether small farms are superior? The evidence is definitely not without its problems and is still attracting academic research, even questioning its existence in settings in which it had previously been taken for granted, such as India's extensively researched ICRISAT village level studies.[3] More importantly, even if the evidence from the studies above can be trusted, it is hardly evidence to settle the issue of whether, on the criterion of growth, smallholdings should be the preferred mode of production rather than larger scale commercial farm enterprises or other modes of production.

The key issue is that the nature of the data examined for most investigations of the inverse productivity relationship in Africa cannot really tell us much about the yields or profitability of large farms: most farms in these data sets are really quite small. Overall, the vast majority of farms in Africa are below 2 hectares, with median farm size near 1 hectare in most countries (Eastwood et al. 2008; World Bank, 2007). Very few large farms are above 5 hectares, let alone those approaching the size of large scale farms in Brazil, or even from Southern Africa, are included in these data sets. The inverse productivity relationship is a celebration of the small farm among *smallholder* farms, and this literature is essentially merely a critique of imperfections in factor markets *within* smallholder agriculture. As a result the evidence that large farming is inefficient is based on extrapolations outside the range of the data. It is thus a weak basis for policy recommendations, even though it is commonly done, as in World Bank (2007).[4] In short, the persistent emphasis on the inverse productivity relationship in the debate on large versus small scale production is methodologically flawed.[5]

This does not mean that smallholders are *not* reasonably efficient in what they do, given the market failures and other constraints they face. The current policy model focuses then on overcoming these constraints for smallholders by a set of policies including extensive interventions in the relevant markets and support services for smallholders, including inputs, extension and finance. But is this model really sufficient to achieve agricultural transformation and rapid production increases, or should other modes of production be considered? We identify three key areas of potential economies of scale that would suggest the current model is flawed.[6] They are: skills and technology, finance and access to capital, and the organization and logistics of trading, marketing and storage. These scale economies are not intrinsic to the size of the farm, but rather to a switch in the form of organization from informal and personalized, to formal and institutionalized. The key benefit of size is that it facilitates (though is by no means synonymous with) *commercialization*. Large, personal 'grandee' farms are liable to be inefficient. Brazilian-style commercial farms are likely to be close to the frontiers of technology, finance and logistics. The innovations of recent decades have made the rapid adaption of technology, access to finance, and high-speed logistics more important, and in the process given commercial agriculture a substantial advantage over the smallholder mode of production. The yield per hectare on family farms of 10 hectares relative to those of one hectare is simply irrelevant to this new world.

The reason why there are few large commercial farms in Africa is not that they would be unable to compete with smallholdings, but primarily that commercial organizations can no longer gain access to land and secondly that the business environment in Africa has in recent decades been more difficult than in competing locations that offered similar agronomic conditions. In turn the difficulties in access to land and doing business have been due

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[3] The empirical validity is still being debated as unobservable land quality, selection issues and measurement error could plausibly account for the evidence in data sets such as the ICRISAT village level data for Southern India (Assunção and Braido, 2007).

[4] How should one then research this issue? We could think of pooling data on smallholders with much larger commercial farmers from otherwise similar settings, if we can find these, and fit a production or yield function to them to investigate the farm size productivity trade-off. For good reasons, few researchers would do this, as it would assume that the 'functional form', i.e. the production technology of such wildly different farms, would actually be the same, even if we manage to control for differences in market failures faced. In short, most would admit that the production processes cannot easily be compared, but still evidence *assuming* the same technology is used to settle the discussion on large farm enterprises compared to smallholder peasant agriculture.

[5] In fact, if anything, the evidence, when taken at face value, suggests that we should aim to make farms much smaller and encourage fragmentation, as this would be more efficient. It makes the case for more careful econometric analysis, accounting for issues such as measurement error of larger plots and farms, and unobserved land quality resulting in selection issues, more important. See for example Assunção and Braido, 2007.

[6] Poulton et al. 2005, or Eastwood et al., 2008 offer longer lists of potential economies of scale in agriculture.

to cultural and political biases rather than to an economic process. Governments were frightened of the emergence of a large class of rural landless workers, and the Western NGOs were hostile to the entire notion of commercial agriculture. Our argument is not that commercial agriculture would always prove to be superior to smallholder agriculture, but that if these impediments were lifted it would probably make a substantial contribution to African agricultural growth.

**Skills and technology**

Scale economies linked to technology are probably the most disputed but also most misunderstood area in the discussion on the virtues of smallholder agriculture. There are plenty of examples of dramatically failed projects of large scale production in agriculture. Some are likely to have more to do with the nature of the organisation (large scale state farms in Tanzania, Ethiopia and elsewhere in the 1970s and 1980s), rather than with factors intrinsic to the technology of agricultural production. Others, such as the infamous groundnut scheme in Tanganyika, Kenya and Northern Rhodesia, started in 1947, tried to import an entire mechanized production technology to areas unsuitable for the technology used.

Some of the misunderstandings stem again from the techniques used to establish returns to scale as they research whether the current technology observed in the data exhibits constant, decreasing and increasing returns to scale. Investigating this question in a setting with few if any large scale producers is unlikely to settle it. Furthermore, using standard production function analysis on cross-section data sets with a predominance of very small producers is unable to identify the dynamic processes of the kind typically linked to increasing returns to scale in the growth literature.[7] Given that production *growth* is what is needed in African agriculture, the key question is not whether in a cross-section, small or larger farms produce proportionately more in this cross-section, but whether they offer a suitable mode of organisation for productivity *growth*.

The underlying requirement for productivity growth via new technologies is obviously the existence of these technologies, such as in the form of seeds or fertilizer. From a strict production point of view, most of these are scale-neutral: there are no agronomic reasons why an HYV seed would grow better as part of a 1 hectare or 50 hectare farm. However, from the availability of new technology to the adoption and efficient use is a huge step, and innovations tend to spread slowly. There are at least two reasons why larger scale farms may be better at the process of adoption: handling knowledge diffusion and managing adoption risks. This is very relevant at the moment, as much attention is going towards stimulating a 'green revolution' for Africa (Sachs, 2005).

Knowledge is a classic scale economies activity replete with externalities. As is well known, any innovation process in agriculture involves *learning*. For example, what is needed by the farmer is adoption of the new technology, but often in conjunction with some adaptation (making the technology work in the specific local context). Most learning in smallholder agriculture is based on extension (mostly via 'model' farmers or village-based field trial plots), on social learning (copying from others) and on combinations of both. Effective learning involves complementary skills such as managerial skills, good numeracy and basic science understanding, and it is commonly observed that there are strong impacts of education on innovation in agriculture (Foster and Rosenzweig, 1996; Haddad et al. 1991; Bandiera and Rasul, 2006). The scarcity of these skills combined with the diverse but specialised skill requirements, make it costly for smallholders to acquire them. Larger organizations are better able to internalize these costs, allowing faster learning. Furthermore, if learning takes place via 'social' learning or copying, then 'noise to signal ratios' may go high, i.e. information flows with error, and information may be poorly transmitted across a large community of smallholders. Again, in a larger

[7] Specifically, standard analysis production function analysis on developing country cross-section data, also in Africa, typically finds non-increasing returns to scale in production, meaning: doubling land operated, labour used and inputs such as fertilizer would result in doubling or less of total output (Ellis, 1994; Eastwood et al., 2008 and the references above). However, these regressions usually cannot account for heterogeneity in overall TFP, unless they can use panel data (e.g. Suri, 2005). Even then, this type of research rarely can offer evidence on the *dynamic* process of productivity growth: the characteristics of farms that allow productivity growth via technology adoption or learning.

organization, learning may be organized systematically with less 'noise' in learning. As a result, in terms of learning, a larger organization may be able to diffuse knowledge much more cheaply, effectively and quickly.

A related issue is that innovation involves risk: entering into something new may involve the need for experimentation and trial and error. As a result, in a community, there are strong incentives to wait until others have tried innovations: one can then pick and choose what really works, with less risk of failure and therefore lower costs. However, the incentive to experiment is then low, and no-one may have an incentive to adopt first, resulting in zero innovation. The underlying problem is effectively a public good problem, resulting in underinvestment in the public good as no-one wants to bear the costs but aims to grab the benefit. Larger farm enterprises can *internalize* these processes: it can afford to use some of its plots for trial and error – and then adopt soon afterwards the successful innovations.

**Finance and access to capital**

Besides economies of scale in innovation and technology adoption processes, commercial farm enterprises have further distinct sources of increasing returns where scale and organization matters: in terms of finance, but also in the organization of production and marketing, such as related to logistics, marketing and storage. These arguments are not simply related to the size of the landholdings of the farm, but also of the nature and scale of the organization of the farm as a commercial enterprise.

The advantages of finance are not simply related to the standard argument that small farmers do not have enough land (or land without enough security) to offer collateral to acquire necessary working capital, while larger farm enterprises may not face these constraints (Eswaran and Kotwal, 1986). While it is probably correct that larger farms have better access to collateral, it is hardly a good argument to favour larger farms, not least once the supervision costs of labour are taken into account: resolving the market failure in credit markets (for example, by using microfinance style organizations), or, as a second best, redistributing land from larger to smaller farmers, as well as allocating property rights to small farmers may in fact be efficiency enhancing (Eswaran and Kotwal, 1986). The argument in favour of larger farm enterprises with respect to finance however is not just about collateral but rather about institutionalization. Like any other commercial organization, a commercial farm builds documented and vetted evidence, such as audited profits and asset valuations that support the accumulation of reputation. It is able to raise capital in a range of complementary forms: equity, bonds and bank borrowing. All this lowers the transactions costs of finance and makes continued access to finance in the face of shocks more likely. Two characteristics of agriculture suggest that these advantages of commercialization are liable to be more pronounced than in industry and services. Agriculture has unusually long lead times between inputs and outputs and so large financing needs, and output is more shock-prone and so reliable access to cover shocks is more important.

**Organization of logistics of trading, marketing and storage**

Finally, larger scale operations can exploit the presence of economies of scale not just in production, but probably most importantly, in trading, marketing, and storage. Storage, wholesale trading and marketing are characterized by technologies that involve economies of scale, via capital but also via the internalization of information. One of the most striking consequences of the model to promote rapid growth in smallholder production is the inherent weakness of the entire interface between producers and the final product market. The underlying 'markets' model is focused on being complementary to smallholders, with the idealized market a large number of relatively small wholesale traders competing across the country and thereby delivering 'efficiency' to markets, with a myriad of small retailers in cities. For both historical and competitive reasons, large traders are viewed with suspicion. Much has been written about stimulating agricultural trade but agricultural markets remain thin, and many have remarked in need of concerted action (Poulton et al. 2006; World Bank, 2007). Poor infrastructure and capital constraints for investment by traders are just some of the arguments proposed to explain these problems. The result is nevertheless continuing high transactions costs in agricultural markets, combined with large price fluctuations, affecting incentives for smallholder productivity growth. The result is also that in most African countries, despite the liberalization of most internal agricultural markets, a variety of donor-supported government initiatives and interventions take place, including in information sharing, storage and credit, again within the simple model of achieving the 'perfect' market with large numbers of small traders. Many have remarked that before the wave of liberalization in the 1980s and 1990s, marketing boards performed many of these functions and some have even called for their reinstatement as the solution (for a discussion, see Barrett and Mutambatsere, 2009).

The underlying model of using government and donor support to encourage the emergence of an agricultural market with many relatively small traders competing is clearly sensible from a static efficiency point of view, but is in denial of inherent returns to scale in the organization of markets. These returns to scale are typically and effectively repressed in these countries, but clearly are a defining feature of agricultural markets in most of the OECD countries. A relatively small number of operators in markets with scale economies ought not to be at the cost of high efficiency and welfare losses, provided there is appropriate competition policy.[8] Larger scale private trading and marketing could reduce costs, possibly via vertical integration or at least coordination, even up to the production side.

Smallholder agriculture is not necessarily inconsistent with the exploitation of scale economies higher up in the value chain, but it does not lend itself to the task. Finding ways to get various more dynamic forms of organizations to flourish, including large scale production operations, or contract farming structures, as well as promoting the exploitation of economies of scale throughout the value chain is bound to provide for a more dynamic agricultural sector. When seen as such, this is not just about the size of the landholdings of producers, but looking for dynamic private farm and marketing organizations, responsive to incentives for growth.

Despite the systematic promotion of the smallholder model, combined with small traders and numerous government support services, the pressures for more dynamic organizational structures are clearly already present in Africa. Globalization has created opportunities for a rapid growth in particular niches of exports, such as in flowers or vegetables, which are taking place on commercial farms, sometimes supplemented with smallholder contract farming, with considerable vertical integration, from production to storage and transport. These processes are largely driven by consumer demands for more standardization and certification, leading to innovations in organizational structures and increased use of long-term contracts at various parts in the supply chain (Pingali et al. 2005).

Increased scale economies in retailing are a central part to this, also affecting Africa: the emergence of supermarkets throughout Africa is also bound to start changing the relationship with farmers as they actively seek vertical integration (Reardon et al., 2003). The real weakness of the current smallholder model is that these more commercial organizations are either looked at with suspicion and threat, or treated as 'another sector', needing to be kept away from the smallholder sector, thereby minimizing the incentives such organizations could have on productivity growth in the smallholder sector.

Keeping them apart is the real mistake: the incentives from long-term contracts and the need for standardization and certification can have large dynamic efficiency gains not least via innovation and knowledge transfer. Evidence from other areas, including from India or transition economies, has shown that vertical integration and coordination is accelerating but also that it can have high returns (Swinnen, 2005; Pingali et al., 2005), and should not just be treated with suspicion.

## 2. GROWTH AND POVERTY REDUCTION: A FOCUS ON SMALLHOLDERS?

Besides a strong believe in the efficiency and dynamism of smallholder agriculture, a commitment to the exclusive smallholder model is often also inspired by a conviction that as poverty in concentrated in rural areas among smallholders, it is essential that any policy that aims to result in lower poverty must start with smallholders. Furthermore, this is argued not to be inconsistent with an overall growth agenda, as growth starting

[8] Textbook principles of competition policy would suggest that competitive pressures from ensuring potential entry, so that new entrants could potentially enter without being deterred by predatory practices in pricing, investment or other practices, are much more important than the number of firms operating in the market.

among smallholders is suggested to have far higher growth 'linkages' than growth in any other sector (e.g. Mellor (1995)). The results in what would seem to be an infallible logic: promoting smallholder agriculture in Africa will lead to growth and reduce poverty better than any other policy. For example, the recent World Development Report 2008 on agriculture stated that stimulating agricultural growth is "vital for stimulating growth in other parts of the economy" and smallholders are at the core to this strategy (World Bank, 2007, p. xiii).

There are more problems with this model than generally tends to be acknowledged. Simply arguing for a sectoral focus because this is where most people or the poor are located is surely a non sequitur: what we ought to aim for is to offer people income earning opportunities while resources in the economy are allocated where the opportunities are highest, and there is little reason to suggest that this must be where labour is allocated at present. Furthermore, taking a longer term view, we know that if we want to have achieved growth and poverty reduction in Africa, we ought to have massive increases in labour productivity and this is bound to include far fewer people in agriculture or indeed being self-employed: poverty reduction tends to involve that most of the lower skilled people have a secure wage-earning job.

The evidence for starting growth in smallholder agriculture is usually based on 'linkages' research, arguing that production and especially demand linkages are stronger from agriculture than any other sector, so that promoting growth in agriculture has the highest multiplier effects (Mellor 1995). If true, this suggests that agricultural growth will tend to stimulate production in other sectors, via its demand effects. This is indeed argued to be the case for Africa (for a review, see Staatz and Dembele, 2007), a view reflected also in the recent World Development Report on agriculture (World Bank, 2007). The evidence is however far weaker than often suggested, and the methods used typically cannot establish any causality, not least in terms of trying to understand where the growth originates (for a detailed review, see Dercon, 2009).[9] This is not to argue that growth in agriculture is not important to the economy, but rather that it ignores how this growth can come about – and that growth dynamics in agriculture typically depend on growth in demand, stemming from other parts of the economy. Wiggins (2000) for example suggested that any periods of rapid productivity growth in agriculture resulted from demand-pressures, in the form of better prices often linked to urbanization and infrastructure. This is (not surprisingly) similar to the evidence on yield growth via innovation in agriculture in England around the time of the industrial revolution: Allen (2009) shows that this largely stemmed from rising food demand pressures resulting from urbanization, with labour-saving technologies developed to offset rising wages.[10]

Most of the reasoning underlying the view that growth must start in the agricultural sector, whether from 'linkages' discussions or more formal basic models such as the Lewis Dual Economy model, are also effectively closed economy models. This seriously qualifies the applicability of the results to current policy. The changing context of globalization, but also of gradually improving infrastructure within Africa, makes it unlikely to be a valid assumption, and, as is well-known, most policy results in favour of a strong bias towards agriculture

[9] The existing literature depends on Social Accounting Matrices, often difficult to compile without much guess work, which are then used to assess linkages. Causal relationships are poorly established, and the evidence, while interesting, can hardly be used to assess what are the actual drivers of growth. Consider for example a recent study by Diao et al. (2007), who present a pair of economy-wide models for Ethiopia, based on parameterizations of input-output coefficients, demand elasticities, and other estimated parameters of the economy. These models are used both to explore the growth impacts of a given, *exogenous* rate of technological improvement in one sector or another, and to compare growth rates required in specific subsectors in order to achieve a given target rate of growth for the economy as a whole. However, these models do not set out to consider the *causes* of growth in these agricultural subsectors (where would these exogenous changes come from?); nor (since they generally make simplifying assumptions about the elasticity of supply from industry or other sectors) do they assess the tradeoffs in resource allocation and the complementarities in demand and production implied. Studies that rely more on econometric evidence do not fare necessarily better. The econometric evidence is affected by simultaneity problems, with little scope for convincing use of instrumental variables, hardly resolved by using panel data (World Bank 2007). It is a research programme with serious inherent difficulties that is not offering the evidence required.

[10] Even the often quoted examples from Asia such as Taiwan or Korea are hard to interpret as if there was a clear sequence from first agriculture and then the rest will follow: other economic processes in other sectors were clearly present and without these it is hard to see how success could have been achieved.

depend on closed-economy assumptions. For certain landlocked economies in Africa with difficult relations with their neighbours, such as Ethiopia, these are reasonable assumptions, but the future comparative advantage for natural resource rich or coastal economies is unlikely to imply that agricultural production will have to lead the growth process. Furthermore, it would be hard to claim that the current geographical spread of smallholder agriculture and food production is likely to be optimal spread of agriculture in a globalizing world facing climate change.

But the argument in favour of promoting smallholders because of its *poverty* impact remains, even if nested within an overall growth strategy that makes agriculture important but not the key sector. For this to matter, we need to focus on labour productivity, as it is directly linked to earnings possibilities. Here, the record for African smallholder agriculture is dismal, with FAOSTAT data suggesting that by 2005, it was still below $500 US per worker for the vast majority of African countries, and growth in labour productivity has been lagging output growth since the 1960s. Even more strikingly is that in countries with a high proportion of output or value added produced by smallholders, these growth figures appear to be especially poor: growth in agriculture has not been delivering labour productivity growth. One of the most careful pieces of evidence on this issue from India suggests a similar process: the highest growth in non-farm earnings and labour productivity did not occur in areas with the highest yield growth (Foster and Rosenzweig, 2004).

This ought not to come as a surprise as the concentration of the labour force in agriculture has remained high, and is only slowly coming down in Africa. If there is going to be a link between poverty reduction and a focus on smallholders, labour productivity will have to be increased, and to achieve this, agriculture has to start engaging in a process of releasing labour via migration. Growth in the rest of the economy is essential for this, but it also important to get labour markets further integrated so that labour productivity gains elsewhere are transmitted across the economy into the rural sector. It is not altogether clear that this is indeed happening in the current agricultural sector dominated by smallholders. Some recent evidence from Tanzania shows migration in action but also how linkages back to the smallholder sector are not delivering much poverty reduction in the rural sector.

Table 1 offers an interesting snapshot of what migration currently means for a poor population. The table (from Beegle et al. 2008) is reporting on a rather unique longitudinal survey. In 1991-94, a survey took place in Kagera, a region in Tanzania near Lake Victoria, in which about 800 households were surveyed. In 2004, a new round took place, but not simply the usual revisit of the same 'households' in the villages they were initially resident. This time all the individuals that were members of any of the original households were tracked, wherever they were. This meant that it became an individual panel data survey, and not just confined to the original villages. In fact, 43% of the surviving individuals were found in other locations, some not too far away, but others hundreds of kilometers away in urban centres across Tanzania and in neighbouring countries. Overall, about 87% of the surviving individuals were traced, resulting in a sample of several thousand households in which these individuals were now residing.

The data provide a relevant perspective on the changes in poverty of this population (based on the consumption per capita of the household in which the individual lives). Table 1 reports poverty headcount levels using a poverty line not dissimilar to the national poverty line in 1991. We report poverty at baseline (1991) and poverty in 2004, and the difference between these levels and its statistical significance. Overall poverty went down from 35% to 27%. But if the survey had been using 'standard' techniques, in which only households and individuals were traced in the original village (e.g. by homestead) then poverty declines would have been far lower, from 36% to 32%. Even more strikingly, the further someone had gone the larger the poverty decline. Those moving out of Kagera experienced the largest declines from 30% to 7%. The data also showed that moving from rural to urban areas had the highest impacts, as well as combining migration with moving from agriculture into non-agriculture as a main activity.

Of course, this is not the same as arguing that migration caused this poverty decline. For example, the standard argument against this is that those who moved were systematically more able to earn higher incomes so the impact of migration is overstated. If they had stayed in the village they would have been better off as well.

Against this, for our purposes, it can simply be noted that a remarkably large percentage of the population moved, and that the migrants are doing particularly well: they did migrate, even if we may believe that they could have done well in their original location. Beegle et al. (2008) analyze these data further with these concerns in mind and find that *ceteris paribus* migrants have 36% higher consumption than similar non-migrants.[11] The improvement in living standards of this previously largely rural based population living off smallholder agriculture was not simply transmitted back into the smallholder economy – earnings seem to remain lagging with limited poverty reduction for those who did not manage to escape.

**Table 1: Poverty and spatial mobility in Kagera, Tanzania**

| *Variable* | *2004 location* | *mean 1991* | *mean 2004* | *difference means* | *N* |
|---|---|---|---|---|---|
| Consumption | within village/neighbourhood | 0.36 | 0.32 | -0.04*** | 2611 |
| poverty | nearby village/area | 0.33 | 0.22 | -0.11*** | 566 |
| Headcount | elsewhere in Kagera | 0.37 | 0.24 | -0.13*** | 571 |
| | out of Kagera | 0.30 | 0.07 | -0.23*** | 327 |
| | full Sample | 0.35 | 0.27 | -0.08*** | 4075 |

Source: Beegle et al. 2008 (***=difference significant at 1%)

This discussion also offers another perspective on the problem of focusing too strongly on smallholder agriculture simply because this is where poverty is located. Rural poverty cannot be looked upon in isolation, and migration in search of a better life has to be seen as an essential and necessary part of policy towards these areas. The evidence above suggests that migration on average has strong effects on poverty. An active policy to reduce poverty which focused on rural areas because this is where people live, or tried to keep people there because of imagined adverse effects of migration, would seem poorly conceived and may even remove a key option for poverty reduction. This is not to say that the marginal return to spending on migration opportunities will always be better than spending on agriculture, but it is a choice that should be considered, not least as the share of the population living off agriculture will have to come down during economic transformation.

Climate change will increase the pressures to accelerate this process. Indeed, since the African climate is deteriorating whereas that in northern Eurasia is improving, Africa is losing comparative advantage in agriculture to other regions. A central part of adaptation policy is therefore for Africa to accelerate its resource reallocation to non-agricultural sectors. Hence, for agricultural policy, and more broadly rural development policy, this offers a striking challenge: policies need to be congruent with creating conditions and opportunities for farmers to leave farming and their current home areas – which is not often a question addressed when discussing smallholder agriculture. But in view of where Africa ought to be in 50 years, with a vast reduction of the labour force in agriculture, it is a question that cannot be ignored.

## 3. SUPERFARMS

Paradoxically, whereas African governments have been hostile to commercial agriculture, they have been surprisingly willing to entertain 'superfarm' deals. In these deals a foreign government, or a company often acting for a government, takes a very long lease on a huge area. China led the way with a multibillion plan to

[11] Beegle et al. (2008) analyze these data further, and suggest that controlling for individual and household fixed effects and a large number of covariates reflecting earning ability, migration still has a strong impact on consumption and poverty. There are some signs that more people leave from families with higher earning ability, but the return to migration controlling for this is still approximately 36%. The evidence shows that moving from rural to urban had highest impacts, as well as moving from agriculture into non-agriculture as a main activity. However, even controlling for these changes, spatial mobility per se still contributed independently to consumption changes.

develop agricultural assets in Africa. Qatar, Abu Dhabi and Saudi Arabia are also actively involved. Headline grabbing private deals such as Daewoo Logistics of South Korea to lease about half the land of Madagascar fuelled the opposition against President Ravalomanana, leading ultimately to a military coup. Another controversial deal is the investment by Heilberg to acquire 400,000 hectares in Mayom district in Southern Sudan by in deal with the warlord and deputy commander of the Southern army.

The buyer motivation for these deals is fundamentally geo-political and arises from the 2008 food crisis, or in a few cases, hedge fund bets on rising land prices in the wake of that crisis. During that crisis many of the governments of food exporting countries imposed export bans in order to protect their urban populations from the rise in the world price of food, even though the bans disadvantaged their own exporters. These export bans exacerbated the rise in world prices by reducing supplies coming onto the world market. In thirty countries there were food riots. In response to the crisis some food-importing countries have drawn the conclusion that they cannot rely upon the world market and must endeavour to 'lock up' some supply major source of supply. This is the rationale for their desire to acquire long term leases on huge tracts of land in Africa on which they would grow food for non-market supply to their home country. Even as a political strategy this is surely doubtful. The notion that the government of an African country would preserve the right of a superfarm to export food to its leaseholding country in a situation in which its own population was going hungry seems implausible.

However, to the extent that it is plausible, the strategy is somewhat similar to the export bans in being beggar-thy-neighbour. The government of Japan, which prefers to depend upon the world market sees superfarms as a threat which should be subject to international regulation.

Regardless of these considerations, are superfarms a sensible approach for an African government? While we have argued above that there is a good case for commercial agriculture, at a larger scale, this does not extend to superfarms.

First, the notion of a 99-year lease is inappropriate given the political and institutional context: there is no credible basis for such very long term commitments, and so the deals are highly likely at some future date to be revoked. Rather than enter into deals with such a high probability of being broken, it would be better to adopt a time horizon that is more realistic.

Second, whatever the scale economies in commercial agriculture, they are highly unlikely to warrant the creation of a huge entity which would inevitably be a monopsonist in local factor markets. Such monopsony positions may be commercially desirable for the leaseholder, but are neither efficient nor advantageous for the host society.

Third, the resulting organizations would be too large to be normal commercial entities. Their rationale is essentially geo-political rather than commercial. Their scale reflects the desire to lock in a sufficiently massive amount of output to achieve food security in the leaseholding country even if this involves a sacrifice of efficiency. Superfarms are thus, more analogous to imperial organizations, such as the groundnuts scheme, than to a globalized commercial agriculture.

Fourth, and most crucially, the processes by which leases have been secured are not competitive. Rather, they are firmly in the tradition of geopolitical deals, with an African ruler, sometimes of limited legitimacy beyond physical control of a territory, mortgaging the distant future in a transaction that is opaque and arrived at through a private negotiation. This is not the right approach for the commercial exploitation of a natural asset such as land. It offers too much scope for corruption on the part of the political leader negotiating the deal, which may indeed account for the willingness of African leaders to entertain the idea. Further, the process is liable to undervalue the asset because the buyer probably has a better idea of potential than the seller. Both problems leave society receiving less that the full social value of the land.

The process which best ensures value for the society is for leases to land to be sold through a transparent auction in which there are several credible commercial bidders each with good technical expertise in using the land productively. The need for multiple bidders reinforces the case against superfarms: the scale of the deal should not be so large as to exclude vigorous competition. Indeed, auction theory suggests that in pioneer situations such as commercial agriculture in Africa, the pioneer firms will initially tend to underbid. As auctions proceed, they generate information as to underlying value which gradually reassures potential purchasers so that the bid price rises over time. Hence, if a country has a large tract of land capable of being used by commercial agriculture, there is a good case for splitting it up into many lots of a few thousand hectares rather than bundling it into a single superfarm, and auctioning the lots gradually over a period of years so that there is time for learning to raise the price.

As noted above, the horizon of the lease should not exceed the credible political horizon. There is a relationship between the process of sale and the credibility of the horizon. The stronger is the reason to believe that the contract has been arrived at honestly and as advantageously for the society as possible, the less likely it is to be abrogated. Hence, with a well-conducted auction the horizon can be somewhat longer, but even so much beyond a decade may initially be implausible.

## 4. CONCLUSION

In recent decades Brazilian agriculture has commercialized and become highly successful in global markets. Currently, Brazilian companies are keen to operate commercial farms in Africa. Should African governments welcome or resist such approaches?

The traditional agricultural literature on Africa, focused almost exclusively on the smallholder mode of production, provides no guide to this decision. The celebration of the small, which is perhaps the dominate motif in this literature, is essentially merely a critique of imperfections in factor markets *within* smallholder agriculture.

The forces which have propelled commercialization in Brazil are that modern agriculture is intensive in new technology, in finance, and in international logistics. Each of these is ill-suited to tiny, self-employed enterprises in which the head has no wealth other than land and little education. African smallholders have not chosen to be entrepreneurs, they are in this activity be default. Having the single most important sector of Africa's economies almost exclusively run by these reluctant micro-entrepreneurs is a recipe for continued divergence of the sector from global agricultural performance. While there is a strong poverty-based case for trying to assist smallholder farmers, the agenda for African agricultural growth should surely be to introduce commercial agriculture on a competitive basis. The approach of consciously excluding commercial agriculture a priori, which has been pursued for the past four decades, has come at a cost. It would be better to let commercial agriculture compete in factor markets against smallholders, while cooperating with them in output markets.

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# REPORT OF THE FAO EXPERT MEETING ON HOW TO FEED THE WORLD IN 2050

**Rome, 24-26 June 2009**

## INTRODUCTION

In the first half of this century, global demand for food, feed and fibre is projected to increase by some 70 percent while, increasingly, crops may also be used for bioenergy and other industrial purposes. New and traditional demand for agricultural produce will thus put growing pressure on already scarce agricultural resources. And while agriculture will be forced to compete for land and water with sprawling urban settlements, it will also be required to serve on other major fronts: adapting to and contributing to the mitigation of climate change, helping preserve natural habitats, and maintaining biodiversity. At the same time, fewer people will be living in rural areas and even fewer will be farmers. They will need new technologies to grow more from less land, with fewer hands.

This scenario raises a number of important questions. For instance, will we be able to produce enough food at affordable prices or will rising food prices drive more of the world's population into poverty and hunger? How much spare capacity in terms of land and water do we have to feed the world in 2050? What are the new technologies that can help us use scarce resources more efficiently, increase and stabilize crop and livestock yields?

Are we investing enough in research and development for breakthroughs to be available in time? Will new technologies be available to the people who will need them most - the poor? How much do we need to invest in order to help agriculture adapt to climate change, and how much can agriculture contribute to mitigating increasing greenhouse gas emissions?

Finally, do we have the right policies to help ensure that the world's future needs are met? Are the governments of the low-income countries adequate to enable their poor and hungry improve their livelihoods and feed themselves? Are trade policies and ODA international cooperation sufficient and properly focused to feed the world better over the coming decades? What are priority areas for policy action and where are the present and future hot-spots where policy action is needed most urgently? What can be done to ensure food security in sub-Saharan Africa, the continent facing the highest population growth rates, the severest impacts from climate change and the heaviest burden of HIV/AIDS?

To consider these and associated questions, FAO convened a three-day meeting of Experts in Rome under the Chairmanship of Hartwig de Haen, former Assistant Director-General with responsibility for the Economic and Social Development Department. 17 papers were commissioned from a broad range of experts and were presented by the authors. A further three presentations were made without supporting papers. Rich discussion followed each presentation.

The meeting was opened by Hafez Ghanem, current Assistant Director-General of the Economic and social development department. It was organized in six sessions matching the structure proposed for the High-Level Expert Forum to be held in Rome on 12-13 October 2009. These are:

1. Global agriculture towards 2050: the outlook for food and agriculture in a dynamically changing economic and demographic environment.
2. Feeding the world in 2050 (1): available resources (land, water, genetics), limits and challenges from climate change and new demands (bioenergy).
3. Feeding the world in 2050 (2): the technological challenge.
4. Feeding the world in 2050 (3): investment needs, sources and the need for a new financial architecture in agriculture.
5. Feeding the world in 2050 (4): the policy challenge – investment, trade, support and more.
6. Feeding the world in 2050 (5): special session on Africa.

The technical papers prepared for the Experts Meeting have been posted on the website at http://www.fao.org/wsfs/forum2050/wsfs-forum/en/ and will be published as a Proceedings document in due course. A synthesis document will be prepared as a basic background document for the High-Level Experts Forum in October.

A list of participants is attached as Annex 1
The agenda is attached as Annex 2

## MAIN MESSAGES AND POLICY PRIORITIES

A key message emerging from the discussions was that it should be possible to produce enough food in 2050 at a global level to feed a world population that has increased to more than nine billion. But this assumed certain conditions are met, and recognized that there are considerable uncertainties, including those related to the impact of climate change and the demand for biofuels on global food supply.

The key condition for meeting the production target participants identified was that there should be increased investment to sustain productivity growth: investment in R&D, technology, infrastructure and institutions, and also in environmental services and sustainable resource management.

The meeting agreed that it was essential not simply to focus on supply issues, but also on the demand side, and the question of access of the world's poor and hungry to the food they need to live active and healthy lives. Furthermore, it would be dangerous to focus exclusively on the aggregate and ignore regional disparities.

Participants agreed that there was a need to improve countries' ability to adapt and respond to new pressures and uncertainties: there was a likelihood of more frequent commodity price spikes in the years ahead, increased volatility in commodity markets, and increased incidence of extreme weather incidents linked to climate change. International trade would be particularly important with several regions forecast to remain in food deficit in 2050.

The policy priorities that emerged from the discussions were:

- increase investment in agriculture;
    - research and development, infrastructure and institutions;
    - also in up- and downstream sectors of primary agriculture, and in complementary sectors such as education and health;
- improve access to food;
    - promote equitable growth in incomes (both farm and non-farm);
    - improve risk management at household and national levels;
    - put in place safety nets for vulnerable groups;
- ensure well-functioning national markets and institutions as well as promoting international trade liberalisation;
    - improve farmers' access to input and output markets while facilitating the transition out of agriculture for those who leave the sector;
    - support the development of value chains benefiting smallholders
    - reduce subsidies for biofuels;
    - reduce trade barriers and
    - improve regulatory frameworks for new technologies, including GMOs;
- improve natural resource management;
    - best practices, sustainability guidelines, payments for environmental services;
- build political will to address challenges that transcend the traditional decision-making horizons of producers, consumers and policy-makers.

## THE DISCUSSIONS

### Session 1: Global agriculture to 2050: how will the world's food and agriculture sector develop in a dynamically changing economic and resource environment?

**Presentations:**

1. Macroeconomic environment, commodity markets: a longer term outlook. Dominique van der Mensbrugghe, Israel Osorio-Rodarte, Andrew Burns, John Baffes, The World Bank.
2. Poverty, growth and inequality over the next 50 year. Evan Hillebrand, University of Kentucky, USA.
3. Agrimonde: scenarios and challenges for feeding the world in 2050. Bruno Dorin, Patrick Caron, Bernard Hubert, CIRAD/INRA.

1. The opening paper noted that the recent commodity boom was the longest and broadest of the post World War II period. Although most prices have declined sharply since their mid-2008 peak, they are still considerably higher than in 2003, when the boom began. Apart from strong and sustained economic growth, the recent boom was fuelled by numerous other factors, including low past investment in extractive commodities, a weak dollar, fiscal expansion in many countries, and possibly investment fund activity. In addition, the diversion of some food commodities to the production of biofuels, adverse weather conditions, global stock declines to historical lows and government policies, including export bans and prohibitive taxes, accelerated the price increases that eventually led to the 2008 rally.

Discussing the macroeconomic environment, the paper noted that over the next 50 years, population expansion would slow down considerably, with an increase of some 50 percent over 2000, but coming off a high base, this still represents a rise of three billion people. There was expected to be nearly no increase in the high-income countries, compared to a 120 percent increase in the least developed countries, many of which have already been having significant difficulty in feeding their growing populations for both natural and man-made reasons.

At the same time, high-income countries have both stable populations and food demand and robust agriculture. This combination could lead to increased reliance of the least developed countries on food imports, with other regions lying somewhere in between – some with surpluses, such as many Latin American countries, and others with potentially growing deficits, as some in Asia. The bottom line is that global agricultural production has to increase at an average rate of 0.8 percent per annum simply to accommodate population growth, and in the least developed countries it would have to grow at an average rate of 1.8 percent over the 50-year period. The authors noted that over the last few decades, which saw a huge increase in world population and stagnant or falling agricultural prices, the growth of supplies was supported by sizeable improvements in agricultural productivity growth – but that this rapid growth has slowed somewhat recently.

On the question of climate change, the paper said that the net impact it was likely to have on agriculture was still being debated, at least at the global level. Some regions, notably the higher latitudes, could benefit from longer growing periods, largely offsetting the damage in regions of the lower latitudes. There was also some uncertainty regarding the impact of carbon fertilization.

Turning to biofuels, the authors noted that the trade-off between food and biofuel feedstock was quite limited in the case of cane-based ethanol. By contrast, ethanol based on grains has a direct effect on the prices of grains as well as of several important competing crops. The expansion of biodiesel has a strong and direct implication for vegetable oil prices and the feedstock and food demand are in direct competition. A large biodiesel expansion would push vegetable prices higher. Hence the expansion of biofuels based on grains and oilseeds is a potentially exacerbating factor for higher food prices and could compromise access to food for the poorest on the planet.

In conclusion the authors said that at a minimum the price spike of 2007/2008 shook global complacency as regards agriculture after an extended period of neglect. Experts were long aware about the fall in agricultural productivity growth and expenditures on research and development, but in a crowded field of international economic policy issues, the warning signs had so far been largely ignored.

Declining population growth and food saturation will temper food demand growth in the future, and there is sufficient land that will allow for some expansion, if managed appropriately and sustainably. It will require investment in infrastructure, which could be onerous, particularly in the poorer parts of the world. The ability to raise productivity is a concern, particularly in an environment with growing climate stress. It will require resources to enhance research and development as well as infrastructure and services, with an emphasis on regions where productivity lags far behind.

2. The starting point for Hillebrand's paper was the fact that global poverty has fallen dramatically over the last two centuries, and the fall has accelerated in recent decades, raising hopes that it could be eliminated within the next 50 years. He noted that if the non-OECD countries merely match the levels of economic growth achieved over the last 25 years, the global poverty ratio will fall from about 21 percent in 2005 to less than 12 percent in 2050, and the number of people living in absolute poverty will decline a further 250 million. If countries matched the levels of economic growth achieved during the height of the globalization boom of 2003-2007, absolute poverty would be wiped out far before then.

However Hillebrand also noted that progress over the last 25 years had not been uniform, and while dramatic improvement was recorded in China and several other large countries such as Indonesia, India, Pakistan, Brazil, Mexico and South Africa, Sub-Saharan Africa as whole saw a huge increase in the number of people living in absolute poverty and only a small decrease in the poverty ratio.

The paper examined two alternative scenarios for the next 40 years: the Market First scenario assumed rapid technological change in the OECD countries, a strong tendency toward convergence in the non-OECD countries based on globalization, pro-growth policies and institutional change. The Trend Growth scenario assumed less technological change, less globalization, and less improvement in economic policies in the slow-growth regions.

Under the Market First scenario, by 2050 the global poverty rate would have been reduced to only 2.5 percent. World food demand in this high-growth, medium-population-growth scenario increases by about 1.3 percent annually to 2050. World supply rises somewhat less because substantial improvements in technology and transportation infrastructure are assumed to cut crop losses sharply. Calories available per person rise everywhere and particularly so in Sub-Saharan Africa.

By contrast, under the Trend Growth scenario, most countries are assumed to continue on the same trajectory they have been on for the last 25 years. For some, notably China and India, this is a very good trajectory. But for Latin America, Africa and the Middle East, it is less so, and by 2050 the rate of extreme poverty in Sub-Saharan Africa is three times what it was estimated to be under the Market First scenario. The Trend Growth calculations assume that the regions that have been lagging do not transition onto a high growth path, which results in much higher poverty levels.

Hillebrand concluded by remarking that even more depressing scenarios had been considered, though not empirically explored, and he noted that resource constraints, if not met by technological solutions, would surely make the poverty estimates in the paper worse. A breakdown in the world market system, or even a gradual turning away from the system that has done so much to reduce global poverty over the last two centuries, would be disastrous.

3. The third paper of the opening session also looked at contrasting scenarios for feeding the world in 2050. The Agrimonde GO scenario focused on feeding the planet by making global economic growth a priority, while the Agrimonde 1 scenario looked at feeding the planet by preserving ecosystems.

Under Agrimonde GO, the world is preoccupied above all with the problem of employing and feeding a growing population. Huge investments in research and infrastructure, especially in developing countries, coupled with free trade, make it possible to meet steep increases in food demand. Economic growth is very intense, surpassing previous averages in several regions – mainly Sub-Saharan Africa and the former Soviet Union – owing to a combination of trade liberalization, extensive economic cooperation and the rapid diffusion of new technologies. In addition, investments in education and health are huge in all regions.

Under this scenario, the global availability of food calories per day and per capita, would increase by 818 calories between 2000 and 2050, with the steepest increases experienced in Asia, sub-Saharan Africa and Latin America.

Under the Agrimonde 1 scenario, global economic growth between 2000 and 2050 is driven by the growth of developing economies. Apart from the spread of ecological intensification practices, an infrastructure of regional planning and supply chains development has been put in place in these economies: transport, storage and industrial processing capacities, as well as services in health, education and training.

Owing to the upsurge of opportunities for wealth creation in rural areas, the rural exodus in developing countries has slowed down. Urbanization nevertheless continues and sometimes encroaches on the best agricultural lands. The acceleration of climate change at the beginning of the century has been a decisive incentive for technological change in agriculture. Ecological intensification technologies make it possible to minimize the environmental impact of agricultural practices, primarily on water, biodiversity and the soil.

Under this scenario, the Agrimonde authors predict that by 2050 diets in the various regions of the world will have converged as regards calorie intake, with a mean availability of about 3,000 kcal per person per day.

**Session 2 - The resource base to 2050: will there be enough land, water and genetic potential to meet future food and biofuel demands?**

**Presentations**

4. World food and agriculture to 1030/3050. Highlights and views from mid-2009. Nikos Alexandratos.
5. World agriculture in a dynamically changing environment: IFPRI's long-term outlook for food and agriculture under additional demand and constraints. Siwa Msangi and Mark Rosegrant, IFPRI.
6. The resource outlook to 2050. By how much do land, water use and crop yields need to increase by 2050? Jelle Bruinsma.
7. How do climate change and bioenergy alter the long-term outlook for food, agriculture and resource availability. Gunther Fischer, IIASA.

4. The first paper in the second session examined the possible evolution of world food and agriculture to 2050 in terms of the key variables – production, consumption and trade of the main commodity groups and the implications for food and nutrition in the developing countries.

The starting point for the analysis was FAO‘s projections of food and agriculture to 2015, 2030 and 2050, with base year 1999-2001, and published in 2006. These projections did not include biofuels. They indicated that all major commodity sectors of world agriculture would grow in the future at lower rates than in the past. The slowdown reflected the lower population growth and the gradual attainment of medium-high levels of per capita consumption in a growing number of countries. The slowdown would contribute to easing the rate at which pressures are mounting on resources and the broader environment from the expansion and intensification of agriculture. However, getting from here to there still involved quantum jumps in the production of several commodities. Moreover the mounting pressure will be increasingly concentrated in countries with low food consumption levels, high population growth rates and often poor agricultural resource endowments. The result could well be enhanced risk of persistent food insecurity for a long time to come in a number of countries in the midst of a world with adequate food supplies and the potential to produce more. Indeed, the analysis of four years ago had indicated that the target of halving the numbers undernourished by 2015 was unlikely to be attained. This prospect was becoming even more likely in the light of developments in recent years when, according to recent FAO estimates, the process of decline in the numbers undernourished, slow and inadequate in itself, was actually reversed.

The author noted that the last few years have witnessed upheavals that must be taken into account in passing judgement as to how relevant the views of the future reflected in the projections of four years ago are today. In the first place, there has been the intrusion of the energy markets into those for agricultural produce via the links of the high energy prices and the boost this gave to the demand for crops as biofuel feedstocks, helped by government policies favouring such use of crops. It is now widely accepted that this was a key factor explaining the food price surges up to mid-2008. Secondly, the overall economic outlook is being severely affected by the ongoing economic crisis, though the issue of how important this may prove for the longer term is moot. He used two criteria to run a reality check of the projections: (a) actual developments over the period 2000-2008, and (b) the latest medium term projections of the *OECD/FAO Agricultural Outlook 2009-2018,* both with and without biofuels. He concluded that on both criteria the projections without biofuels of four years ago for broad commodity and country group aggregates were still broadly valid.

The advent of biofuels represented a new element in the long term outlook and needed to be integrated into the standard projections of food and feed. The projected slowdown in the growth of world agriculture might be significantly mitigated or even reversed if the use of crop biomass for biofuels were to be further increased and consolidated. Existing biofuels projections for the medium term indicated that the demand from this source for food crops might be contained. However, much depended on developments in the energy markets. The assumption was often made that second generation biofuels would be coming on stream in about two decades. This might ease the food-biofuels competition but would not eliminate it, since biomass production for second generation biofuels would still compete for the common land and water resources.

If the biofuels sector were to expand significantly, the implications for agriculture, development and food security could be significant: it could give a boost to the development prospects of countries with abundant land and climate resources that are suitable for the feedstock crops. Several countries in Latin America, South-East Asia and sub-Saharan Africa, including some of the most needy and food-insecure ones, could benefit. Whether and to what extend this may happen is very uncertain, but the issue deserves serious analysis and evaluation. Of particular interest would be the possible adverse effects on the food security of the poor and the food-insecure if food prices were to rise because of resource diversion towards the production of feedstock crops for biofuels, and also the environmental implications of cultivated land expansion into pasturelands and forested areas.

5. The second paper, from IFPRI, explored the nature of several key drivers of change in food systems, and examined a number of possible entry points for policy interventions, in order to determine their effect on food prices and other market-driven outcomes. The authors said that the sharp increases in food prices that have occurred in global and national markets over the last several years have sharpened the awareness of policy-makers and agricultural economic analysts to the stresses facing the global food systems and the ecosystems that support them. The rapid increases in prices of key food commodities such as maize, wheat, rice and soybeans among others has mirrored the increase in prices of energy products and strengthen the recognition that energy and agricultural markets are becoming more closely linked.

The authors said that while many see the reversal of historically declining real prices of agricultural commodities as an opportunity for agricultural producers in both developed and developing countries, others remain concerned about the implications of high food prices and increased volatility in food markets on the welfare and well-being of vulnerable populations. IFPRI’s projections indicated that world grain prices were likely to increase further by between 30 and 50 percent before 2050, and meat prices by an additional 20-30 percent beyond current high levels.

The paper said that the challenges and increased stresses that face global food production and distribution systems are particularly acute and pressing for sub-Saharan Africa, where high and persistent levels of food insecurity already exist, with roughly a third of the population having insufficient access to food and 43 percent living below the international poverty line. The constraints that lie in the way of Africa benefiting from higher producer prices of agricultural commodities on the world market are myriad, and include the fact that most of sub-Saharan Africa’s agricultural production relies on rainfed cultivation and receives lower input levels of improved seed technology and fertilizer applications than other regions.

The paper said that the main socio-economic factors that drive increasing food demand are population increases, rising incomes and increasing urbanization. The combination of these latter two factors is also changing the nature of diets. Rapidly rising incomes in the developing world have led to an increase in demand for meat products, which in turn puts additional pressure on land resources for pasture and coarse grain markets for feed, including maize.

The authors stated that increases in population and income increase pressure on natural resources to meet domestic, agricultural and industrial demand. Climate change and increasing demand for water resources will impact growing conditions, significantly impacting food production in the future. Developing countries are likely to have a 9-21 percent decline in potential overall agricultural productivity due to global warming. Already yield growth rates for major grains have been declining in recent decades and have dropped by roughly 50 percent from the highs of the 1960s and 1970s. One of the causes of this decline was undoubtedly a fall the growth of public agricultural research and development spending, down by 51 percent in real terms in the two decades since the 1980s.

Turning to policy responses, the authors said that on the demand side, policies governing the use of food-based feedstocks for biofuel production could be altered to promote use of non-food feedstocks. On the supply side the urgent need was to boost cereals output by raising yields through policies that accelerate the improvement of crop technologies, including investing in irrigation systems.

The paper concluded by arguing that certain policies should be avoided when countries are faced with high food prices, in particular export bans, import subsidies and restoration of production subsidies. Instead policy-makers should focus on eliminating trade barriers, revitalising agricultural growth by expanding aid for rural infrastructure, services, research and technology, and ensuring safety nets are in place to shield the most vulnerable.

6. The Bruinsma paper focused on the additional demands on natural resources to meet the crop production levels in 2030 and 2050 projected by FAO in 2006. It concluded that growth in agricultural production will continue to slow down as a consequence of the slowdown in population growth and of the fact that an ever increasing share of world population is reaching medium to high levels of food consumption. Nevertheless, agricultural production would still need to increase by 70 percent overall and nearly 100 percent in developing countries by 2050 to meet the demand associated with a 40 percent increase in world population, in the process raising average food availability to 3,130 kcal per person per day. This translates into an additional billion tonnes of cereals and 200 million tonnes of meat to be produced annually by 2050.

The paper estimated that 90 percent of the growth in crop production would come from higher yields and increased cropping intensity, with the remainder coming from land expansion. Arable land would expand by some 70 million ha overall (less than 5 percent), with an expansion of 120 million ha in developing countries being offset by a decline of some 50 million ha in developed countries. Most of the expansion would take place in sub-Saharan Africa and Latin America.

Discussing the feasibility of the projected increases in land, water use and yields that are needed, the author noted that the Agro-Ecological Zone study shows that there are still ample land resources globally with some potential for crop production. The availability of fresh water resources shows a similar picture with supplies more than sufficient globally, but very unevenly distributed, with an increasing number of countries or regions within countries reaching alarming levels of water scarcity.

The potential to raise crop yields even with existing technology seemed to be considerable. Provided the appropriate socio-economic incentives are in place, there are still ample bridgeable gaps in yields, especially in developing countries.

Despite this potential, the paper concludes that all is not well. The fact that the world as a whole produces or could produce enough food for all is small consolation to the persons and countries (or regions within countries) that continue to suffer from undernourishment. The projected increases in yields, land and irrigation expansion will not come about solely as a result of market forces but will also require huge public intervention and investments, particularly in agricultural research and in preventing and mitigating environmental damage. In the problem countries, public intervention will continue to be required on the one hand to develop agriculture and to adapt agriculture to local circumstances, and on the other hand to establish social safety nets.

7. Gunther Fischer presented the main themes of IIASA's Biofuels and Food Security Study, which included a review of world-wide biofuels development and policy support; assessment of the agro-ecological potential of first and second generation biofuel feedstocks; scenarios of first and second generation targets to 2020 and 2030; and impacts of biofuel expansion on food prices, agricultural value added, land use, and greenhouse gas emissions.

Analysing the likely positive, neutral and negative effects of global environmental change of agro-ecosystems, Fischer noted that global warming was likely to remove cool temperature limitations in some areas, particularly in higher latitudes, allowing longer growing seasons and faster growing periods. However it was also likely to result in temperatures exceeding thresholds for some crops, increases in crop water requirements and increased incidence of plant pests and disease, particularly in tropical regions. Changes in the composition of the atmosphere could result in crop yield increases as a result of CO2 fertilization and improvements in the efficiency of water use, but also increases in pollution. Further impacts could include changes in rainfall patterns, in soil moisture and surface runoff; increased occurrence of extreme weather events; and increased climate variability.

The study showed that the impacts of climate change on crop production are geographically very unevenly distributed, so that aggregate global figures reveal little. It predicted that autonomous adaptation, by shifting planting dates, changing cultivars, moist-conservation tillage, use of irrigation where economical, and switching crops, would offset some of the effects of gradual warming. The aggregate impacts of projected climate change on the global food system were thus relatively small, and the global balance of food demand and supply was not likely to be challenged until the middle of the century.

However the study also indicated that while atmospheric changes, and in particular CO2 fertilization, may initially increase the productivity of current agricultural land in the temperate latitudes, climate change, if not halted, would have a clearly negative impact in the second half of this century. It noted that changes in the frequencies of extreme events such as droughts, heat waves or severe storms would be more troublesome in the short term than gradual changes in average condition. It warned however that the impact of climate change on increasing the demand for irrigation water could be as large as the changes predicted due to socio-economic developments in the period to 2080.

Summarizing the study and associated scenarios, Fischer said that the conclusion was that there would be strong increases in global demand for agriculture products – up about 70 percent in 2050 compared to 2000. There was expected to be increasing integration of agriculture, forestry and energy sectors through land competition for biomass production. There was limited availability of additional high quality land, and uncertainty regarding the viability of using marginal land. Finally there was growing risk of yield damage due to extreme weather episodes, and widespread negative climate change impacts could be expected after the middle of the century.

**Session 3 – The investment challenge to 2050: how much, where to invest, what priorities and what sources?**

**Presentations:**

8. Investment requirements under new demands on world agriculture: feeding the world with bioenergy and climate change. Siwa Msangi and Mark Rosegrant, IFPRI.
9. Capital requirements for developing countries' agriculture to 2050. Josef Schmidhuber, FAO.
10. Drivers of investment in large-scale farming: evidence and implications. Klaus Deininger, Derek Bylerlee. World Bank.
11. International investments in agricultural production in developing countries: win-win or neocolonialism. David Hallam, FAO

8. The Msangi-Rosegrant paper stated that the results of the authors' analysis revealed a significant level of investment needed for key regions such as sub-Saharan Africa and South Asia, which hold most of the world's poor and undernourished and which will be hard hit by climate change. The role of irrigation was particularly important for those regions, like Africa, which depend heavily on rainfed agricultural production, and the need for roads also becomes important as a means of increasing market access.

The paper warned that reduced investment in crop and energy technology over time could lead to a longer term slowdown in the expansion of supply, eventually leading to higher prices as demand begins to grow faster. It noted that agricultural research dedicated to improving the productivity of staple crops had declined over the years as the United States and other developed regions shifted their research focus to reflect consumer preferences for processed, organic and humane products. This had slowed the diffusion of more relevant yield enhancing technology on developing countries. Better technology diffusion0 and more public money dedicated to developing country research programmes were critical to meeting growing food needs.

The message for policy-makers was that a combination of policy interventions was needed, to accelerate yield growth, increase commitments towards Research and Development from both private and public sources, and improve extension services and marketing and distribution infrastructure.

9. Schmidhuber's paper analysed the capital requirements for agriculture in developing countries to 2050, and concluded that there was an average annual requirement of some USD 210 billion gross, and USD 83 billion net, excluding the depreciation and replacement costs, at constant 2009 dollars. This resulted cumulatively in a gross investment requirement over the next 44 years of nearly USD 9.2 trillion to deliver the production increases projected by FAO. The author noted that a striking feature of the outlook was that the annual net additions to the capital stock showed a noticeable decline over time, resulting in a slowdown in the annual net requirement. The analysis suggested that overall growth would be characterized by a growing substitution of labour with capital and moderate total factor productivity growth. There would be marked regional differences, however. In Latin America growth would be capital and productivity based, with negative labour contributions, while in Sub-Saharan Africa, it would be heavily labour and only moderately capital based, with limited efficiency gains.

The analysis of expected revenues, capital stocks and land available per labourer suggested that many people in sub-Saharan Africa would remain dependent on labour-intensive, capital-saving forms of small-scale agriculture, in which many farmers will have too few resources and revenues to share. The paper said that the available capital stock per worker was identified as an important explanatory variable for inter-regional differences in performance. A farmer in Latin America has on average 10 times more capital available than his counterpart in sub-Saharan Africa. Latin American farmers also enjoy better infrastructure, research institutions, roads and electricity.

The paper said the regional disparities and the outlook for Africa posed questions as to alternative income sources that might be tapped. Emerging options included opportunities arising from higher energy prices and production of bioenergy feedstocks; income opportunities from the provision of environmental services; and a greater export orientation.

10. Derek Byerlee gave a presentation of preliminary findings of a World Bank study looking at the drivers of international investment in large-scale corporate farming. There was no accompanying paper. The study had set out to discover what was really happening on the ground; whether the policy, legal and institutional environment was adequate; were these sound investments; and what social and environmental impact were they having. He said such investments involved opportunities and risks. On the positive side there was the prospect of using abundant land in remote regions, of developing exports, of moving into new industries such as biofuels, of generating employment and transferring technology. But the risks included lack of attention to existing land users, undermining governance, short-term interests and negative environmental impact.

The study's initial findings were that the trend to large investment in farms in developing countries was not new, and it took many forms. It appeared that there were more proposals than approved deals, and that many investments were speculative. Analysis had identified elements of a conducive policy framework for such investments that started from a clear definition of land rights and policies for transfer and joint ventures. There needed to be land available with potential for development, and clear process for the acquisition or transfer of public and private land wit6h appropriate compensation. Investors needed transparency in the supply and approval procedure, and institutional roles needed to be clear and coordinated. And finally there needed to be sensible environmental and social safeguards.

For the future, Byerlee said the interest in land acquisition was likely to continue, with some governments very active and with deep pockets. Developing countries needed to develop the capacity to manage the process better, and there was considerable interest mainly from the investor side, in the development of a Code of Conduct.

11. David Hallam's paper also looked at the recent resurgence of interest in international investment in agricultural land. He noted that purchases and leasing of agricultural land in Africa by investors in various Gulf States for food production in support of their food security strategy had perhaps attracted most attention, but were in fact just one of a variety of actual or planned investment flows. The paper noted that complex and controversial issues – economic, political, institutional, legal and ethical – were raised in relation to food security, poverty reduction, rural development, technology and access to resources, especially land, in the country offering the land.

Hallam said that investor motivation varied, but included portfolio diversification and biofuel production as well as food security, reflecting a fear arising from the recent high food prices and policy-induced shocks that dependence on world markets for food supplies has become more risky. Investors seek enhanced food security for themselves by acquiring land and water resources in countries where they are more abundant. He noted that many investors sought to buy land, since titled ownership of assets was seen as most secure, but there were many arguments against this from the point of view of the host country. Acquisition of land does not necessarily provide immunity to sovereign risk, and can provoke political and economic conflict, the paper said. Other forms of investment such as contract farming and out-grower schemes can offer just as much security of supply.

Turning to the benefits of these investments, Hallam said the financial benefits to host countries might be small, but there was a potential for providing developmental benefits through technology transfer, employment creation, infrastructural provisions, production increases, and export earnings. But he warned that there were additional political and ethical concerns where the host country was food insecure. While there was a presumption that investments would increase aggregate food supplies, this did not imply that domestic food availability would increase, notably where food produced was repatriated to the investing country.

The paper said that if the general developmental benefits of international investments were to be realised, then appropriate policy, institutional and legislative frameworks needed to be in place to guarantee them. Apart from the financial terms and conditions, provisions may be needed covering local sourcing of inputs, including labour, social and environmental standards, property rights and stakeholder involvement, food security concerns, distribution of food produced between export and local markets, and distribution of revenues. Trade policy was also involved where investors wanted to repatriate food produced and some countries had offered trade policy exceptions such as agreements not to impose export controls even in times of domestic food crisis. The case for an international code of conduct which highlighted the need for transparency, stakeholder involvement and sustainability, and emphasised concerns for domestic food security and rural development, needed to be explored.

**Session 4: The investment challenge and the technology challenge to 2050**

**Presentations:**

12. Foreign Direct Investment and other forms of TNC participation in agricultural production: trends and implications. Hafiz Mirza and Anne Mirous, UNCTAD
13. Investment in developing countries' food and agriculture: assessing agricultural capital stocks and their impact on productivity. Gustavo Anriquez, FAO, Hartwig de Haen, Oleg Mivyevskiy and Stephan von Cramon-Tauadel, University of Gottingen.
14. Can technology deliver on the yield challenge to 2050? R.A. Fischer, Derek Byerlee, G.O. Edmeades.
15. Setting meaningful investment targets in agricultural research and development: challenges, opportunities and fiscal realities. Nienke Beintema, Howard Elliott, IFPRI.

12. Hafiz Mirza presented UNCTAD analysis of the involvement of trans-national companies in investing in developing countries, demonstrating how companies are active at all points in the global value

chain, from input supply, seed propagation, production on the farm, basic processing, trading and logistics, processing and retailing. There was particular interest in making direct investment in land, either through outright ownership, the preferred option, or long-term leases. Generally it was the policy of the host country that determined the form of land tenure. But at the same time there was a discernible trend to short, medium and long-term contract farming arrangements.

UNCTAD's figures showed that while the trend of overall FDI to agriculture, forestry and fishing was fairly flat, there had been a significant increase in the food and beverage sector (including tobacco) in the last few years. The main products targeted by trans-nationals included corn, cotton, dairy products, floriculture and fruits, meat and oil crops, rice, soybeans, sugarcane, vegetables and wheat. Most of the investing companies were based in United States and Europe, but also some North African and Middle Eastern countries, China and South Africa.

13. Stephan Cramon and colleagues reported that the fixed capital stock (ACS) in primary agriculture has been growing at global level over the last three decades, although for most of this period at a declining rate. At the same time there seemed to be a shift in the relative share of capital formation between different regions and country groups. The paper clarified that the productive capacity of the food and agriculture sector entailed not only the physical assets at farm level, but also the working capital in the form of fertilizer, seeds and pesticides used in the production process, public rural infrastructure, capacities in science, technology and extension services, productive capacities in up and downstream sectors throughout the agricultural commodity chain, as well as human and social capital.

The paper noted that annual rates of growth in the stock of improved agricultural land have been declining at global level over the period. This could reflect, at least in part, a reduction in the willingness to invest in improving the productivity of the existing stock of land. The authors noted that ACS had grown the least in countries with the highest prevalence and depth of hunger. In several of the least developed countries, in particular in Sub-Saharan Africa and South Asia, the growth of the population active in agriculture had outstripped the rate of ACS growth. This development was particularly worrying because it severely limited these countries' ability to increase labour productivity in rural areas and hence to reduce poverty and undernourishment. By contrast, countries making the most progress towards reaching the World Food Summit target of halving the number of undernourished citizens by 2015 have realized relatively high rates of growth of ACS per worker in agriculture.

At the same time they found a direct correlation between government expenditure on agriculture and capital formation in a sample of developing countries. This correlation confirmed the decisive role of public expenditure in creating an enabling environment in terms of infrastructure and sustainable access to natural resources. Public expenditure on agriculture could be an important ingredient in an investment climate conducive to agricultural development and the reduction of hunger. This finding should be a strong signal for governments in developing countries to change priorities in budget allocations so as to avoid, or at least reduce, any existing discrimination towards agriculture

The authors remarked that a common feature of countries that had been successful in reducing hunger and poverty was that they not only had higher overall rates of economic growth than the less successful countries, but that they achieved this higher growth through a relatively higher growth in agriculture. Other features were an absence of conflict, good governance, functioning markets, public investment in rural infrastructure and a greater degree of integration in world markets than the less successful countries. Such success stories could be found in all regions.

14. Tony Fischer and colleagues started from the premise that given land and water scarcity, climate change and rising energy prices on the supply side, and growing markets for food, feed and fuel on the demand side, global grain markets will be tighter in the future than over the past 40 years. Given that area expansion will at best be small, agricultural growth will be more reliant than ever on raising crop and animal yields. However the growth rate of cereal yields has been falling since the Green Revolution years.

Changes in global yields were important for global food security. In a globalizing world, many countries will increasingly depend on trade to provision their food needs, which should encourage production in the lowest cost regions, barring significant trade barriers. However there are many situations where trade will be inadequate to assure food supplies. India and China, for example, would have little choice but to produce most of their staple foods, especially rice, given relatively small world markets in relation to their huge domestic markets. In Africa too, poor infrastructure, landlocked location and lack of foreign exchange necessitated that much of the food be produced near where it is to be consumed. The high population growth in some of the more densely populated African countries places an additional urgency on accelerating domestic production.

The paper analyzed the gap between yields achieved in research stations and on the farm, in several crops and different regions. It concluded that despite impressive gains in yields over the past 50 years in most of the world, large and economically exploitable yield gaps remained in many places, especially in the developing world and nowhere more so than in sub-Saharan Africa where food supply is most precarious. The authors stated that in the short to medium terms there were many technologies that are in their early stage of adoption that promised a win-win combination of enhancing productivity and sustainably managing natural resources. These included conservation farming approaches based on no tillage and the GM technology revolution – both still only used on less than 10 percent of the world's cropland.

However yield gains could not be achieved by technology alone, but also required complementary changes in policies and institutions. Innovations were required in risk management, market development, rural finance, organizing farmers, and provision of advisory services. Overall the authors said they were optimistic of the world's ability to feed itself in 2050, but the history of agriculture in the 20th century teaches us that investment in R&D will be the most important determinant. Resilience, flexibility and policies that favour R&D investment in staple food research and efficient input use will be the pillars on which future food security depends.

15. Beintema and Elliott reported that global public spending on agricultural R&D, including government, non-profit and higher education sectors, totalled some USD 25 billion in 2005 dollars in 2000, the latest date for which comparable global data are available. This was a considerable increase on the USD 16 billion reported in 1981, but growth was not even across regions. Spending in the Asia-Pacific region more than doubled, while in contrast spending in sub-Saharan Africa only grew on average by 0.6 percent annually. More worrisome is that spending for sub-Saharan Africa as a whole actually contracted slightly during the 1990s, with more than half the countries for which data is available spending less in 2000 than they were in 1991.

The authors found that the government sector is still the largest contributor to public agricultural research, accounting on average for 81 percent of total funding, although in sub-Saharan Africa some 35 percent of funding was received from donor loans and grants. They noted that the Comprehensive Africa Agriculture Development Programme committed countries to double the current annual spending on agriculture research within 10 years, which would mean an average 10 percent annual increase – substantially higher than the average 1 percent seen in the 1990s.

The authors stated that in order to reverse the general under-investment, meet various political targets and prepare for emerging challenges in the coming decades, more investment was clearly needed. But they warned that this presumed that there was sufficient research capacity to address the targets, or the commitment to invest what is needed in developing that capacity. The rate at which research capacity can grow is linked to the strength of the higher education system, which itself requires retooling.

Regarding the focus of new investment in R&D, the paper said the options lie in areas where new knowledge, science and technology are needed to meet pre-stated goals of environmental sustainability, economically sustainable development, hunger and poverty reduction, and improving nutrition and human health. It noted that there were some areas where the challenges were likely to grow with climate change, population growth and increasing resource scarcity. It also urged greater involvement of women and called for policies that encourage the increased participation of women, not only to secure gender balance, but also to tap substantial additional human resources for agricultural R&D.

**Session 5: Feeding the world in 2050: the global policy challenge**

**Presentations:**

16. Evolving structure of world agricultural trade and requirements for new world trade rules. Alexander Sarris, FAO
17. Farm support policies that minimize global distortionary effects. Aziz Elbehri and Alexander Sarris, FAO

16. Alexander Sarris said that the recent world food crisis of 2007-2008 had alerted the world and policy-makers to the fact that global agricultural productivity growth has been slowing down, and highlighted the fact that current national agricultural trade policies and the current world trade rules as agreed in the WTO Agreement on Agriculture, may not be adequate to prevent such crises in the future. At the same time, changes in climate may be the precursors of more potential food crises, with significant negative impacts on many poor across the world. This necessitated a reconsideration of the factors that drive long-term agricultural trade and the needs of future global agricultural trade rules.

The paper defined the causes of the recent food price spike as being growing world demand for basic food commodities; demand for cereals for biofuel production; the rise in petroleum process; slowing rates of increase in farm productivity; the gradual decline in global food commodity stocks; commodity speculation, and macroeconomic factors such as US dollar depreciation. It also pointed to a tendency towards hoarding and panic buying and the imposition of policies affecting the normal flow of commodities.

The medium-term outlook for agricultural commodities is that while the growth rate of world demand would slow in the next 10 years, demand for income sensitive products will grow faster. Growth in food demand will be faster in developing countries for all types of products and supply is expected to keep up, with moderate increases in productivity. Nevertheless new demands especially for biofuels are likely to keep prices firm in the medium term. The overall conclusion is that global food commodity markets are likely to stay volatile in the next few years until stocks are replenished, petroleum prices stabilize and the global financial crisis works itself out.

Looking at the effects of price volatility, Sarris said that price instability can undermine the perceived legitimacy of the global market as a place in which countries can buy food supplies on a regular basis and make use of trade to supplement domestic production. The WTO rules were currently unbalanced in that they spring into action when prices are low but do little to constrain government action when prices rise. So export subsidies are constrained and tariffs are bound, but export taxes are not limited and export embargoes hardly mentioned. The ability of the world trade system to respond in times of price volatility is likely to be tested severely in the future, and some creative institutional arrangements may be needed.

In his conclusion Sarris noted that many developing countries and especially LDC countries in Africa, have become more food import dependent without becoming more productive in their own agricultural producing sectors, or without expanding other export sectors to be able to pay for that import dependency. This implies that they may have become more exposed to international market instability and hence more vulnerable. Given population growth patterns and income projections, the largest challenge in the coming decades seems to be to ensure a global trading system that balances the objective of an orderly and dependable market for food with the objective of growth of many currently developing and least developed countries.

Sarris took the opportunity of his presentation to discuss components of a possible International Grain Clearing Arrangement to guarantee the performance of medium and long-term grain contracts between countries or private entities, and also a proposal to ensure food imports in low income net grain importing countries through a dedicated Food Import Financing Facility.

17. Aziz Elbehri noted that in OECD countries, farm support policies stimulate domestic production, but also create distortions in world markets, inducing disincentives in developing countries' agricultural production in the long run. He noted that OECD farm policies were changing and perhaps reducing their degree of market distortion. At the same time developing countries were not affected uniformly by OECD policies as a result of differentiated selective trade preference between countries. A key challenge was how

to shape and design support to farmers in both developed and developing countries without hurting the farmers in the developing world and at the same time promoting global food security.

The paper discussed a range of policies which might be non-distorting. It noted that farm policies in developed countries have progressed towards decoupled payments, and said this should be further encouraged. It suggested that agricultural insurance in OECD countries should deal only with extreme and unpredictable agricultural risks that cause market failures. It urged decoupled policies to maintain agricultural production reserves in high income countries through policies such as set-aside, as an alternative to expensive physical commodity reserves.

In developing countries there should be promotion of public and private sector investment strategies with an emphasis on public goods type investments such as infrastructure and technology. There should also be a focus on the input side, developing the infrastructure for supply of inputs such as seed and fertilizer, and promoting input subsidies. Trade policies should be used selectively to support and complement domestic investment programmes. Risk reduction and risk coping policies in developing countries should be promoted and carbon offsets in developed countries should be used to promote carbon reducing but at the same time productivity enhancing agricultural technologies and investments in developing countries.

The paper said the largest trade distortions were created by market access restrictions imposed by OECD countries on agricultural imports and these restrictions should be lowered significantly, particularly as regards the least developed countries. Such restrictions, in the form of tariff barriers, standards, phytosanitary restrictions etc. significantly impacted developing country trade. The author also urged flexibility for developing countries and especially LDCs in the Doha Round, and suggested that OECD countries might offer compensatory financing for developing country producers, perhaps by putting a percentage of farm subsidies into a global development fund. The paper also urged the promotion of a Food Import Financing Facility to insure LIFDCs against sudden and adverse movements in the food import bills, and urged the promotion of a market-based and more automatic compensation scheme for negative agricultural earnings variations for commodity-dependent low income countries.

**Session 6: Africa's special role, problems and needs: what development model for Africa?**

**Presentations:**

18. Challenges and opportunities for African agriculture and food security. Hans P. Binswanger-Mkhize, Tschwane University.
19. Can the smallholder model deliver poverty reduction and food security for a rapidly growing population in Africa? Steve Wiggins, ODI.
20. African agriculture in 50 years: smallholders in a rapidly changing world? Paul Collier and Stefan Dercon, Oxford University.

18. Binswanger opened his paper and presentation with an upbeat assessment of future prospects for Africa, stating that after decades of decline of per capita food production, we are now in a period of new optimism about the prospects for Africa and African agriculture. Economic growth was near 4 percent, agricultural growth about 1 percent, armed conflicts were down and democracy had advanced significantly. The paper analyzed the causes of Africa's failure to grow as rapidly as the rest of the developing world in past decades, which had left a terrible legacy of poverty and hunger.

The paper said that the higher food prices of recent years meant African agriculture was likely to become more profitable. It noted that the resumption of overall economic growth and agricultural growth had not been caused by significant investments in infrastructure, any closing of the agriculture technology gap or the provision of better services to smallholders. Private input and output markets had not developed as fast as expected and farmers continued to be severely penalized by inadequate competition in these markets and by higher input prices and lower farm-gate prices than in other regions of the world. Binswanger also noted that growth had resumed despite continued high population growth, the AIDS crisis and the onset of measurable climate change. Indeed, he stated that higher world prices combined with rapid demand growth associated with population growth, urbanization and income growth opened the greatest opportunities for African farmers in domestic and regional markets

Examining the impact of climate change, the paper said that depending on whether carbon fertilization benefits materialized, the aggregate negative impact of climate change on potential African agricultural output up to the 2080-2100 period was estimated to be between 15 and 30 percent. Since the specific nature and severity of changes were not known, it was not possible to plan specific measures for mitigating the effects, instead what was required was a strengthening of the capacity of African agriculture and food systems to adapt to climate change, through improved technology generation and adoption systems, more and better irrigation and drainage, better markets and greater ability to import food in bad years or on a year-round basis, greater preparedness for extreme weather events and better safety nets.

Examining the demographic question, the paper said rapid population growth was not only a drag on growth, but also generated huge unemployment problems among youth. Agricultural development should be seen as an opportunity to generate much more employment for rural youth and thereby stem urbanization. But it added that while the demographic transition had barely begun in Sub-Saharan Africa, faster economic growth, high female education, and a resumption of family programmes could significantly accelerate it, thereby creating a population dividend for future economic and agricultural growth.

Binswanger concluded with a four point agenda for action: countries should avoid backsliding on economy-wide and agricultural policies and further reduce disprotection where still practiced; barriers to intra-regional trade in food and other agricultural commodities should be reduced and institutions supporting regional trade, quality and phytosanitary controls and other regional agricultural public goods and services should be properly financed; domestic and regional funding should be increased for agricultural science, science education and research; domestic markets should be assisted to deepen and sharp improvements in smallholder services should be fostered.

19. The Wiggins paper and presentation examined the debate about which agricultural model was most likely to secure agricultural growth in Sub-Saharan Africa – smallholders or commercial farming. Wiggins stated that the empirical record of performance of both small and large farms in Africa was uneven and incomplete, which made analysis difficult, and there were significant regional variations in performance. He noted that there was broad understanding that the combination of creating a favourable investment climate, spending on public goods, fostering of economic institutions, the presence of demand at the farm gate, and conservation of natural resources were necessary. He also noted that agricultural supply chains were changing, with ever more demanding conditions being imposed on would-be suppliers that could marginalise small farms.

Wiggins conceded that the disappointing record of African agricultural development in many but not all countries over the last 30 years or more years, not surprisingly invited doubts about the ability of the predominantly smallholder structure of farming across the continent to deliver agricultural development. The essential conditions for smallholder development included a favourable investment climate for farming, and the creation of a level playing field in which farmers could buy inputs, access finance and sell their produce on something like neutral terms in which they were not exorbitantly taxed by domestic policy, albeit implicitly, or having to compete with subsidized food imports, or exporting to markets where prices had been depressed by the policies of OECD countries.

A second key condition was investment in public goods that support agriculture, most notably agricultural research and extension, rural roads, education, health care and in some cases irrigation and power supplies. The third key condition was the development of economic institutions to allocate and protect property rights, to facilitate trading, to reduce risk and allow collective action. And, of course, there was a need for the existence of demand that was transmitted effectively to the farm gate.

Since not all small farmers would be able to participate in growth to the same degree, the options for policy-makers came down to the three Dorwood choices: Stepping up, Stepping out, or Hanging in. The uppermost quartile would be those stepping up, while those stepping out would need to be helped to move into the non-farm economy, while those hanging in would require safety net support. The final conclusion was that smallholder development could help deliver food security in Africa. More food availability was likely to tend to push down food prices, while increased incomes for the poor were likely to mean greater access to food. But this would not be sufficient. A substantial part of the problem of child malnutrition in areas such as West

Africa came from disease, not food supply. For better nutrition, the continent needed to do as much to ensure access to clean water, sanitation and primary health measures, as to grow more food.

20. In the final presentation, Paul Collier opened with an alternative vision of a successful Africa in fifty years time, characterized by a vast reduction in the number of people engaged in agriculture, a massive increase in the urban and coastal populations, a vast reduction in the size of the population living in rural areas relatively far from urban areas and the coasts, a considerable increase in labour productivity in agriculture, and a considerable increase in overall agricultural production. This contrasted with the current character of much of African agriculture: a vast and only slowly changing number of poor smallholders contributing most of agricultural output, with low yields, limited commercialization, few signs of rapid productivity growth, and population-land ratios that are not declining.

Collier noted that climate change strongly reinforced the need for African agriculture to adapt. If it was to be successful despite overall deteriorating agro-climatic conditions, new crops or varieties would need to be grown, often using different technologies. Furthermore the geographical distribution of agricultural activity would have to change. Collier asked whether the current model favoured by donors and most agricultural economists was likely to achieve the needed transformation. Its approach was to stimulate growth in smallholder agriculture by a variety of interventions from technology to market development. Collier and his co-author questioned this model, arguing that the perceived wisdom of the likely success of this strategy was based on weaker evidence than is commonly suggested. They believed that without considering more radical strategies, Africa's agricultural growth prospects might be weak. The alternative was not to return to the discredited 1950s and 1960s models of mechanized agriculture, but to consider more flexible organizational models in which not all bets were placed on a single unquestioned model of production.

The paper argued that much of the focus on smallholders might actually be hindering large-scale poverty reductions, and current policy ignored one key necessity for labour productivity growth: successful migration out of agriculture and rural areas. Collier identified three key areas where larger farms would benefit from economies of scale, which together suggested that the current model was flawed. These were skills and technology, finance and access to capital, and the organization and logistics of trading, marketing and storage. What was needed was a switch in the form of organization from informal and personalized to formal and institutionalized. The benefit of size was that it facilitated commercialization. The innovations of recent decades had made the rapid adoption of technology, access to finance, and high-speed logistics more important, and in the process given commercial agriculture a substantial advantage over the smallholder mode of production.

Collier argued that the reason there were few large commercial farms in Africa was not that they would be unable to compete with smallholdings, but primarily that commercial organizations can no longer gain access to land, and secondly that the business environment in Africa has in recent decades been more difficult than in competing locations that offered similar agronomic conditions. Difficulties in access to land and doing business have been due to cultural and political biases, rather than to an economic process. Collier said Governments were wary of the emergence of a large class of rural landless workers, and the Western NGOs were hostile to the entire notion of commercial agriculture. The belief of the authors was not that commercial agriculture would always prove to be superior to smallholder agriculture, but that if these impediments were lifted it would probably make a substantial contribution to African agricultural growth.

In conclusion the paper noted that in recent decades Brazilian agriculture had commercialized and become highly successful in global markets, propelled by intensive use of technology, finance and international logistics. Each of these elements were ill-suited to tiny, self-employed enterprises in which the head had no wealth other than land and little education. While there was a strong poverty-based case for trying to assist smallholder farmers, the agenda for African agricultural growth should surely be to introduce commercial agriculture on a competitive basis. The approach of consciously excluding commercial agriculture *a priori*, which has been pursued for the past four decades, had come at a cost. It would be better to let commercial agriculture compete in factor markets with smallholders, while cooperating with them in output markets.

## CONCLUSIONS

### Crisis-proofing the world food system

Following the formal presentations, the Chair invited participants to make proposals for concrete policy actions that could address the issues identified during the meeting and ensure that the world can indeed provide food security to all its citizens by the year 2050.

The Chair asked participants to focus on what needed to be done, who should do it, and how policy should differ from in the past. Following is a distillation of contributions.

### 1. Investment

All participants agreed on the need for significant new and increased investment to secure the needed agricultural development, and in particular growth in yields, in productivity and production. The established correlation between spending on Research and Development and yield growth meant that R&D was an important focus of investment, particularly in developing countries. The CGIAR system needed revitalising. There was also a need for investment in improving market access both upstream and downstream, in rural infrastructure, in extension services, in risk management and rural finance, and in institutions and capacity development. Countries need to create an investment climate that would attract the private sector to participate. There was general agreement on the need for a code of conduct to manage the trend towards large international investments in farming in developing countries.

### 2. Access

The question of access to food was as important as supply, so that simply producing enough food on aggregate was not a solution to feeding the world's expanded population in 2050. There were other ingredients to resolving problems of undernourishment such as clean water, sanitation and education, particularly of women. It was recognized that while this meeting had focused on supply-side issues and broad global developments, the gender dimension was critical to the issue of increasing agricultural production and productivity and improving access to food.

### 3. Trade

There was agreement that the world commodity trading scene was likely to remain volatile and that price spikes could become more frequent. There was a problem of loss of confidence in the market by some importers to be addressed. Proposals were made for a clearing house system and a financing mechanism for poor countries. There was agreement that trade liberalisation and completion of the Doha Round were vital, and that efforts should be made to reduce the distortionary effects of farm support policies in OECD countries. Participants supported the proposal for a link between farm support in the OECD and a fund to assist developing countries farmers. Many agreed that efforts should be made to dissuade countries from imposing export bans, perhaps by bringing such moves under the WTO rules.

### 4. Africa

While some participants debated the traditional smallholder model for African agricultural development , with proposals for removing barriers to larger commercial farming and improving opportunities for the poorest subsistence farmers outside agriculture as well as within it, others maintained that smallholders, if given the adequate conducive socio-economic environment, would still have an important role in Africa's future.

## 5. Climate Change, bioenergy and technology

The new challenges of climate change and the demand for bioenergy feedstock meant new solutions should be considered. Since the exact effect of climate change could not be known, the important thing was to enhance the capacity of countries to respond. There was agreement that the suite of tools needed to meet the challenge would include the use of GMOs. In developing countries the argument for using GMOs was that by increasing and stabilizing yields they could be life-saving, rather than simply cost-cutting, which was the driver in developed countries. There was a need to help developing countries put in place regulatory processes that would facilitate the roll-out of GM crops.

## 6. Institutions

Many participants called for an institutional revolution to ensure that farmers and others receive the support and incentives they need at all stages in the value chain. Historical fiscal discrimination against agriculture should be ended.

## LIST OF PARTICIPANTS

## FAO EXPERT MEETING ON HOW TO FEED THE WORLD IN 2050, 24-26 JUNE 2009

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**FAO EXPERT MEETING ON HOW TO FEED THE WORLD IN 2050, 24-26 JUNE 2009, FAO HEADQUARTERS, ROME (MEXICO ROOM)**

# AGENDA

**WEDNESDAY, 24 June 2009**

| | |
|---|---|
| 09.30 – 10.00 | Welcome Address (Hafez Ghanem) |
| 10.00 – 13.00 | **Session 1:** **Global agriculture to 2050: How will the world's food and agriculture sector develop in a dynamically changing economic and resource environment?** |
| | ▪ The macroeconomic environment, commodity markets: A longer term outlook. (Presenters: Dominique van der Mensbrugghe, John Baffes; World Bank)<br>▪ Poverty, growth and inequality over the next 50 years. (Presenter: Evan Hillebrand, University of Kentucky)<br>▪ Agrimonde: Scenarios and challenges for feeding the world in 2050 (Presenters: Bruno Dorin, Patrick Caron, Bernard Hubert, CIRAD/INRA) |
| | |
| 14.30 – 17.30 | **Session 2**: **The resource base to 2050: Will there be enough land, water and genetic potential to meet future food and biofuel demands?** |
| | ▪ World food and agriculture to 2030/2050. Highlights and views from mid-2009 (Presenter: Nikos Alexandratos, FAO)<br>▪ World agriculture in a dynamically-changing environment: IFPRI's long-term outlook for food and agriculture under additional demand and constraints (Presenter: Siwa Msangi, IFPRI)<br>▪ The resource outlook to 2050. By how much do land, water use and crop yields need to increase by 2050? (Presenter: Jelle Bruinsma, FAO)<br>▪ How do climate change and bioenergy alter the long-term outlook for food, agriculture and resource availability (Presenter: Günther Fischer, IIASA) |

**THURSDAY, 25 June 2009**

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| 09.00 – 12.30 | **Session 3:**<br>**The investment challenge to 2050: How much, where to invest, what priorities and what sources?** |
| | ▪ Investment requirements under new demands on world agriculture: Feeding the world with bioenergy and climate change (Presenter: Siwa Msangi, IFPRI)<br>▪ Capital requirements for developing countries' agriculture to 2050. (Presenter: Josef Schmidhuber, FAO)<br>▪ Drivers of investment in large-scale farming: Evidence and implications (Presenter: Derek Byerlee, The World Bank)<br>▪ Investment in developing countries' food and agriculture: Assessing agricultural capital stocks and their impact on productivity (Presenter: Stephan Cramon, University of Goettingen) |
| | |
| 14.00 – 17.30 | **Session 4**:<br>**The investment challenge and the technology challenge to 2050** |
| | ▪ International investments in agricultural production in developing countries. Win-win or neo-colonialism? (Presenter: David Hallam, FAO)<br>▪ Foreign direct investment and other forms of TNC participation in agricultural production: Trends and implications. (Presenter: Hafiz Mirza, UNCTAD)<br>▪ How can technology deliver for food crop yields (Presenter: Tony Fischer, CSIRO)<br>▪ Setting meaningful investment targets in agricultural development: Challenges, opportunities, and fiscal realities (Presenters: Nienke Beintema, Howard Elliott, IFPRI) |

**FRIDAY, 26 June 2009**

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| 09.00 – 12.30 | **Session 5:** **Feeding the world in 2050: The global policy challenge** |
| | ▪ Presentation 5.1: World agricultural trade challenges to 2050 and requirements for evolving structure of world trade rules compatible with food security for developing countries (Presenter: Alexander Sarris, FAO)<br>▪ Presentation 5.2: The role of non-distorting support policies for long-term agricultural development (Presenter: Aziz Elbehri, FAO) |
| | *Lunch* |
| 14.00 – 17.30 | **Session 6**: **Africa's special role, problems and needs: What development model for Africa?** |
| | ▪ Presentation 6.1: How can Africa master its multiple challenges of high population growth, climate change and HIV/AIDS (Presenter: Hans Binswanger-Mkhize, Tshwane University of Technology)<br>▪ Presentation 6.2: Can the smallholder model deliver poverty reduction and food security for a rapidly growing population in Africa? (Presenter: Steve Wiggins, ODI)<br>▪ Presentation 6.3: African agriculture in 50 years: Smallholders in a rapidly changing world? (Presenter: Paul Collier, Oxford University |
| | **Concluding discussion, outlook and summary of the chair** |

Food and Agriculture Organization of the United Nations

*for a world without hunger*

# HOW TO FEED THE WORLD 2050 EXPERT MEETING

24-26 June 2009 FAO headquarters, Rome

Disclaimer
List of abbreviations
Agenda
Expert papers
Meeting report
List of participants



Expert Meeting on
**How to Feed the World in 2050**
24-26 June 2009, FAO headquarters, Rome (Mexico Room)

**AGENDA**

| | | |
|---|---|---|
| **WEDNESDAY, 24 June 2009** | | |
| 09.30 – 10.00 | Welcome Address (Hafez Ghanem) | |
| 10.00 – 13.00 | **Session 1: Global agriculture to 2050: How will the world's food and agriculture sector develop in a dynamically changing economic and resource environment?** | |
| | | The macroeconomic environment, commodity markets: A longer term outlook. (Presenters: Dominique van der Mensbrugghe, John Baffes; World Bank)<br>Poverty, growth and inequality over the next 50 years. (Presenter: Evan Hillebrand, University of Kentucky)<br>Agrimonde: Scenarios and challenges for feeding the world in 2050 (Presenters: Bruno Dorin, Patrick Caron, Bernard Hubert, CIRAD/INRA) |
| 14.30 – 17.30 | **Session 2: The resource base to 2050: Will there be enough land, water and genetic potential to meet future food and biofuel demands?** | |
| | | World food and agriculture to 2030/2050. Highlights and views from mid-2009 (Presenter: Nikos Alexandratos, FAO)<br>World agriculture in a dynamically-changing environment: IFPRI's long-term outlook for food and agriculture under additional demand and constraints (Presenter: Siwa Msangi, IFPRI)<br>The resource outlook to 2050. By how much do land, water use and crop yields need to increase by 2050? (Presenter: Jelle Bruinsma, FAO)<br>How do climate change and bioenergy alter the long-term outlook for food, agriculture and resource availability (Presenter: Günther Fischer, IIASA) |
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| | **Concluding discussion, outlook and summary of the chair** | |

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