Foreword

The purpose of this book is to investigate the relationship between agricultural investment and productivity in developing countries. Investment is viewed as an important aspect to enhance agricultural productivity, and the key to promoting long-term growth. Although technology and policy are other important long-term factors, the book focuses on investment because public, private and international investments are declining. Low levels of investment in agriculture bode poorly for long-term prospects of achieving food security in the developing world. A growing agricultural sector contributes to overall growth and improved food security in developing countries where the agricultural sector provides livelihood directly and indirectly to a significant portion of the population, especially in rural areas, where poverty is more pronounced. Hence, improving the production capacity of agriculture in developing countries through productivity increases is a critical component of improved food security. The objective of this book is to provide an understanding of the linkages between agricultural investment and productivity where agricultural investment includes not only investments in physical capital but in human and social capital as well as natural resources.

The book reviews studies investigating the relationship between investment and productivity, as well as highlights some new findings, methodology and data issues. The book is divided into three sections. The first section focuses on the methods developed and overall findings about the relationship between investment and productivity. Special emphasis is placed on a methodology for incorporating agricultural natural resource depletion in calculating measures of growth. The first paper, *Agricultural Investment, Production Capacity and Productivity,* by Zepeda, provides an overview of the terminology, different methods used in the analysis of measurement of productivity and a review of the productivity literature. This provides background and context for the subsequent papers. Paper 2, *An International Analysis of Agricultural Productivity,* by Chavas, is an international comparison of agricultural productivity of selected countries from 1961 to 1994. A non-parametric method is used to illustrate how this approach can be used with both cross-section and time-series data. Paper 3, *Agricultural Productivity and Natural Resource Depletion,* by Lee and Zepeda, presents a model that incorporates natural resource depletion. Until now, models of productivity measurement have not taken this into account even though many economists recognize the importance of environmental disinvestment. The paper outlines a methodology for incorporating this analysis as well as data needs.

The second section of the book provides more detail on regional differences in the relationship between agricultural productivity and investment among developing countries. The factors that enhance and limit production growth are examined, with an emphasis on investment needs. These factors include the amount and quality of inputs, how they are combined (i.e. technology), human ability or expertise in implementing technology (human capital), environmental factors and agricultural policies. Paper 4, *Agricultural Productivity for Sustainable Food Security in Sub-Saharan Africa,* by Wiebe, Soule and Schimmelpfennig, focuses on sub-Saharan Africa, comparing partial and total measures of productivity among the countries in the region. Paper 5 by Chang and Zepeda, entitled *Agricultural Productivity for Sustainable Food Security in Asia and the Pacific,* examines trends in Asia and the Pacific, looking at how the region compares to other regions in partial and total productivity as well as how returns to public and private investment compare. Paper 6, *Agricultural Production in Peru (1950-1995): Sources of Growth*, by Velazco is an exploration of how agricultural production and investment have evolved over time in Peru in the context of land policy, civil unrest, debt and structural adjustment. The role of investment is estimated using production and supply functions.

The third and final section examines the relationship between policy, investment and productivity. Two case studies are presented to examine the factors affecting agricultural growth and individual decisions to invest in agriculture. Paper 7, *A Comparison of Commercial and Smallholder Sectors in Zimbabwe and South Africa,* by Wiebe, Schimmelpfennig and Soule, is a meso-level analysis of investment among small and commercial agricultural producers in Zimbabwe and South Africa. Paper 8, *Determinants of Agricultural Investment by Small-Scale Producers in Peru,* by Velazco and Zepeda is a micro-level analysis of individual agricultural producers in the Highlands of central Peru and their motives to invest. This final section emphasizes how characteristics of agricultural producers can influence the incentives to invest and therefore the need to accommodate for heterogeneity in the development and implementation of policy. It also identifies where there are gaps in national data on the investments of small producers.

Overall the book provides an overview of current thinking and findings about the relationship between agricultural investment and productivity. This includes theoretical and methodological developments, such as incorporating natural resource depletion. It also underlines, through the concerns expressed by many authors about data scarcity and limitations, that neglect of information needs hampers the forward-looking assessment of sustainability of agricultural and rural development. The book also reviews findings about the linkages of investment and productivity in the context of other important factors such as land policy, debt, civil unrest and structural adjustment programmes. This places agricultural investment solidly as a crucial but integral component of an overall policy to promote agricultural productivity.

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Contents

Section I
Agricultural productivity growth and investment: issues and methods

1. Agricultural investment, production capacity and productivity

Lydia Zepeda

This chapter provides an overview of current economic thinking on some aspects of agricultural investment and productivity, especially in the context of developing countries. While the importance of physical capital has long been recognized, economic research has identified human capital formation as a crucial, productive element of investment, both in its own right and as a complementary input to physical capital and other inputs. Human capital may be embedded in the inputs that go into production or may enhance the way inputs are utilized and combined. Current economic research also highlights the importance of taking into account the sustainability of agricultural production systems. Resource economists have identified the need to calibrate agricultural production for negative environmental externalities and resource depletion to represent the true value of agricultural output. The upshot of current economic thinking is that the analysis of investment in agriculture should encompass more than just physical capital formation. In order to examine the linkages between agricultural investment and agricultural production capacity and productivity, agricultural investment must include both human capital formation and environmental degradation.

1.1 Introduction

Improving the production capacity of agriculture in developing countries through productivity increases is an important policy goal where agriculture represents an important sector in the economy. The agricultural sector provides livelihood directly and indirectly to a significant portion of the population of all developing countries, especially in rural areas, where poverty is more pronounced. Thus, a growing agricultural sector contributes to both overall growth and poverty alleviation.

Within the context of growth in food and agriculture, emphasis is placed on productivity because expansion of arable land is very limited in most countries due to physical lack of suitable land and/or because of environmental priorities. In addition, the difference between actual and technically feasible yields for most crops implies great potential for increasing food and agriculture production through improvements in productivity, even without further advances in technology.

Investment is of special interest as a limiting factor to agricultural production capacity and production because an alarming trend is being observed: public and private investment in agriculture has been declining (World Food Summit (WFS), 1996a). The decline in public investment is of particular concern because public investment in basic infrastructure, human capital formation and research and development (R&D) are necessary conditions for private investment. (Antholt, 1994; Evenson and McKinsey, 1991; Pray and Evenson, 1991; Pardey Roseboom and Craig, 1992). Public investments also promote technology adoption, stimulate complementary on-farm investment and input use and are needed for marketing the agricultural goods produced (Feder, Just and Zilberman, 1985; Nelson, 1964 and 1981; Nelson and Phelps, 1966; Rahm and Huffman, 1984; Rogers and Stanfield, 1968; Wozniak, 1989).

This paper provides an overview of the economic terminology, research findings, modelling techniques and their limitations that are used to link agricultural investment to output and productivity. After an introduction to the basic concepts and terminology of agricultural productivity and investment in the next section, the paper introduces three methodological approaches used to measure production growth, along with their advantages and disadvantages. In Section 1.4 findings from various agricultural growth studies are presented, focusing on the linkage between different types of agricultural investments and growth. Section 1.5 addresses the data needs and limitations in measuring the linkages between investments and growth in agriculture. These are of particular importance because data availability can limit the type of analysis done and consequently the questions that can be answered regarding agricultural growth and productivity. Concluding remarks are presented in the final section.

1.2 Terminology

This section describes economic terminology used throughout the book and commonly used in studies of agricultural growth.

Agricultural productivity

Agricultural products are usually measured by weight or volume. An immediate question arises as to how to best combine different agricultural products since summing over weights or volumes is not very meaningful. One approach when dealing with crops is to convert them to a common physical unit, such as wheat units (Hayami and Ruttan, 1985; Block 1994). More commonly, *aggregate* output in agriculture is measured in monetary units as the sum of the value of all production in the agricultural sector minus the value of intermediate inputs originating within the agricultural sector. Both cash and non-cash (barter, trade and self-consumption) transactions of final products should be included. This is referred to as "final output" and differs from agricultural GDP by not subtracting out the value of non-agricultural inputs (Rao, 1993). In other words, final output is the amount of agricultural output available for the rest of the economy, while agricultural GDP measures the net contribution of agriculture to the GDP of a country.

Productivity measures are subdivided into partial or total measures. Partial measures are the amount of output per unit of a particular input. Commonly used partial measures are yield (output per unit of land), labour productivity (output per economically active person (EAP) or per agricultural person-hour). Yield is commonly used to assess the success of new production practices or technology. Labour productivity is often used as a means of comparing the productivity of sectors within or across economies. It is also used as an indicator of rural welfare or living standards since it reflects the ability to acquire income through sale of agricultural goods or agricultural production (Block, 1995).

Partial measures of productivity can be misleading, as there is no clear indicator of why they change. For example, land and labour productivity may rise due to increased use of tractors, fertilizer or output mix (move to high value crops). To account for at least some of those problems a total measure of productivity, the Total Factor Productivity (TFP) was devised. TFP is the ratio of an index of agricultural output to an index of agricultural inputs. The index of agricultural output is a value-weighted sum of all agricultural production components. The index of agricultural inputs is the value-weighted sum of conventional agricultural inputs. These generally include land, labour, physical capital, livestock and chemical fertilizers and pesticides. Growth in TFP is referred to as the Solow residual. It is generally considered a measure of technological progress that can be attributed to changes in agricultural research and development (R&D), extension services, human capital development such as education and physical, commercial infrastructure, as well as government policies and environmental degradation (Ahearn *et al.*, 1998). Change in TFP can also be due to unmeasured inputs or imperfectly measured inputs.

Investment

Investment is the change in fixed inputs used in a production process. In the most narrow definition, investment is the change in the physical capital stock, that is, physical inputs that have a useful life of one year or longer (land, equipment, machinery, storage facilities, livestock). However, Eisner (1985) estimated that less than 20 percent of total growth in the United States comes from physical capital formation, while Denison's (1967) estimates were 10 to 15 percent.

Economists recognize that, though difficult to measure, a comprehensive agricultural investment measure should include improvements in land, development of natural resources and development of human and social capital in addition to physical capital formation. Human capital is the stock of knowledge, expertise or management ability. Since it is directly influenced by educational, training and extension institutions, variables such as education level or extension contacts are often used as proxy measures. Public and private expenditures on R &D are often used to proxy the level of human capital as well. Coen and Eisner (1987) specifically include R&D, education and training as forms of human capital investment.

Social capital is the stock of personal relationships and knowledge of institutions that an individual or household has. This affects the individual's access to risk minimizing inputs like credit, insurance and land title. In other words, social capital measures the ability to utilize social networks and institutions. Status, gender and group affiliations are often used as proxies for social capital in economic studies. However, education and transportation, as well as the range of social institutions available, can also influence social capital.

Asymmetry of investment and risk

A key characteristic of investment is its irreversibility, often referred to as asymmetry (Nelson, Braden and Roh, 1989). Once investments are made, there are few other productive activities for which they can be used. Dixit and Pindyck (1994) formulate the problem of the irreversibility of investment under uncertainty as the decision to pay a sunk cost and in return receive an asset with a value that can fluctuate. They demonstrate that under uncertainty actual investment will always be less than the expected present value of investment, the difference being attributable to the irreversibility of industry specific investments.

Agro-climatic factors may exacerbate the asymmetry of agricultural investment, as is the case when the land is suitable only for a particular crop. Other forms of investment, such as tractors and farm machinery have few other alternative uses besides agriculture, while human and social capital particular to agriculture may not adapt well to other sectors. Contrast this with investments made in capital markets or even factories. The former can be moved around to the most profitable enterprise, while, in general, the latter can be modified to produce more profitable products. Due to this fixity of agricultural assets and the uncertainty it entails, farmers are often reluctant to invest in equipment, land improvements or human capital. Uncertainty may cause the level of investment to be "sub-optimal", resulting in deteriorating physical and human capital and mining of soil nutrients.

Drawing on fixed asset theory, Nelson, Braden and Roh (1989) hypothesize that it is more difficult to dispose of capital specific to agricultural production than to add to the stock of specialized capital. This implies that periods of disinvestment (through depreciation) will be greater than those of investment in agriculture. Thus, in any given year net agricultural investment is likely to be negative (depreciation is higher than gross investment). Because investment is irreversible, farmers only invest during years when profits are high and/or borrowing costs are low.

Rosenzweig and Binswanger (1993) find that agricultural investment behaviour of farmers reflects their risk aversion, with poorer farmers accepting lower returns in exchange for lower risk to smooth their consumption. The wealthy are less risk averse; they can afford to accept higher risk in seeking higher returns. Hence, they find that wealthier farmers, particularly those with larger farms and diversified incomes, have higher rates of farm investment on a per hectare basis. They suggest that consumption credit and/or crop insurance would increase the overall profitability of agricultural investments.

Public expenditures and investment in agriculture

Public expenditures on agriculture include short-term costs as well as long-term investments. Investment in agriculture and forestry includes government expenditures directed to agricultural infrastructure, research and development and education and training. Data on the proportion of all central government expenditures spent on agriculture and forestry are incomplete, particularly for African countries. Comparisons between developed and developing countries reveal that there is greater variation among developing countries than industrial countries. In industrial countries in 1992, the range of expenditures was between 0.4 to 9.1 percent, with most countries clustered around 1.5 percent. For those developing countries reporting, agricultural expenditures were between 1.5 to 7.9 percent in Africa, 1.7 to 23 percent in Latin America and 0.20 to 19 percent in Asia (IMF, 1995). As a percentage of expenditures, agricultural expenditures generally declined from 1988 to 1993 in Africa, Eastern Europe and industrialized nations, declined for some Asian countries, increased for China and were mixed for Latin America.

Human capital development is a key component of public agricultural investment. Judd, Boyce and Evenson (1991) examined the role of public expenditures in agricultural research and extension on agricultural output. They show that between 1959 and 1980, real spending on research and extension programs increased by factors of four to seven and that research intensities more than tripled for the lowest income developing countries. They show a decrease in the disparity between countries over time. They estimate world agricultural research public-sector expenditures at US$7.4 thousand million and world public sector agricultural extension expenditures at US$3.4 thousand million (both in 1980 dollars). Africa had the smallest share of world research expenditures (5.7 percent) and human resources (5.5 percent), yet a larger share of world extension expenditures (14.8 percent) than Asia and the second largest world share of extension human resources (20.7 percent). Calculating public sector expenditures as a percent of agricultural product, Africa's expenditures are higher than those of South and Southeast Asia.

The composition as well as the amount of public expenditure on agriculture is also of concern. As early as 1978, an FAO study identified a lack of investment in education and training in developing countries as an impediment to agricultural growth (Beal, 1978). In absolute and relative terms, expenditures on education and training by developing countries were less than those of developed countries. Beal proposed a target for education expenditures of at least 4.6 percent of GNP (the developed country average) and at least one field level extension worker per 1000 farm families.

1.3 Measuring agricultural productivity

Models of production growth have been used to measure the change in output, to identify the relative contribution of different inputs to output growth and to identify the Solow residual or output growth not due to increases in inputs.

Three different types of economic models have been used to investigate production growth: (i) index numbers or growth accounting techniques, (ii) econometric estimation of production relationships and (iii) nonparametric approaches. Each approach can be used to measure aggregate agricultural output or TFP. Each approach has different data requirements, is suitable for addressing different questions and has strengths and weaknesses.

Growth accounting involves compiling detailed accounts of inputs and outputs, aggregating them into input and output indices to calculate a TFP index (Diewert, 1976, 1980, 1981). The initial focus of growth accounting studies in the 1950s and 1960s was on partial measures of growth; only capital and labour were examined. However, growth accounting methods were unable to demonstrate much of a link between the amount of physical capital formation and output growth (Denison, 1987). Denison's (1967) growth accounting study of the 1950s and 1960s determined only 10 to 15 percent of growth could be accounted for by capital formation in non-residential plant and equipment (Cornwall, 1987). Nor did Bosworth (1982) find much of a role of reduced capital formation in the economic stagnation of the 1970s. Work by Abramovitz (1956), Solow (1957) and Kendrick (1973) "showed beyond reasonable doubt that the modern growth of the United States economy was in proportionate terms at least three-quarters due to increased efficiency in the use of productive inputs and not to the growth in the quantity of resource inputs per se " (Metcalfe, 1987). This implied that quality of inputs matters more than quantity.

The failure of economics in the 1950s, 1960s and 1970s to find strong relationships between capital formation and economic growth was due in part to a narrow definition of capital formation and partly due to failure to control for other inputs. The unexplained growth was of the order of half the change in real output. Subsequent studies have tried to close this gap by including more inputs (fertilizer, pesticides, etc.), or finding ways to quantify inputs (human capital) for the analysis. The Solow residual has been referred to as efficiency, technological progress, economies of scale, or a "measure of our ignorance" (Cornwall, 1987).

During the 1990s, there was a revival of interest in "new growth accounting" approaches, including endogenous growth models. The resurgence of interest in growth models has come in part from researchers incorporating omitted variables in their analysis, particularly measures of human capital, and new developments in the theory of growth. Hsieh (1998) developed a dual approach to computing the Solow residual using the growth in input prices rather than input quantities. Endogenous growth theory incorporates R&D as an intermediate input in the production process (Romer's [1990] varieties model) or views technological progress as improvements in the quality or cost of intermediate inputs (Grossman and Helpman's [1991] quality ladder model). Obsolescence in technology differentiates the quality ladder model from the varieties model (Barro, 1999). Both models contain endogenously driven technological change and exogenous technological change.

The econometric approach is based on econometric estimation of the production technology, either the production function (primal approach) or a cost function (dual approach) (Antle and Capalbo, 1988). The econometric approach started in the 1970s in response to the weak findings of the growth accounting approach. The idea was that one might find stronger relationships if one estimated production relations directly while employing less restrictive assumptions regarding aggregation and production technology (Capalbo and Vo, 1988). This approach also permits quantifying the marginal contribution of each category of inputs to aggregate production. For example, one can determine the impact of a one-percent increase in fertilizer use on overall agricultural output, holding all other inputs constant. Additionally, with the flexible functional form one does not impose as restrictive assumptions about technology as the accounting approaches. The general form of a flexible production function is:

$$\ln Q = a_0 + a_t T + \Sigma_{i=1} a_i \ln X_i + (1/2)\Sigma_{i=1}\Sigma_{j=1} g_{ij} \ln X_i \ln X_j + \Sigma_{i=1} f_{it} \ln X_i T + (1/2) f_{tt} T^2$$

where Q is an aggregate output index, T is a time trend representing technological change and X_i is a quantity index of input category i. For theoretical consistency, symmetry and hometheticity are imposed. However, to maintain sufficient degrees of freedom and to mitigate multicollinearity problems, it may be necessary to aggregate input data into a small number of categories. To avoid this, many researchers use the Cobb-Douglas function, despite the fact that it imposes some assumptions about technology, such as unitary elasticity of substitution. Capalbo (1988) compares econometric models that impose different assumptions about technology to estimate technological change, returns to scale and TFP in United States agriculture 1948-1982.

The application of endogenous growth theory using econometric approaches has focused on cross-country comparisons of the entire economy. These new growth models have been able to explain growth better than the old growth models. Using data from 1960 to 1985 for 98 countries, Mankiw, Romer and Weil (1992) augment a Solow model with a human capital variable to examine international variation in per capital GDP in three categories of countries (non-oil, intermediate and OECD). Even with a restrictive Cobb-Douglas functional form, they are able to capture about 80 percent of the variation in GDP among non-OECD countries. Using cross-section data from 98 countries on growth between 1960 and 1985, Barro (1991) incorporates both a human capital measure and population growth (arguing that raising the cost of children reduces fertility rates and increases investment in both physical and human capital). Barro finds that the returns to physical capital investment are positive but inelastic; a one-percent increase in the ratio of investment to GDP increases real growth in GDP by less than one percent. Levine and Renelt (1992) examine the average annual growth between 1960 and 1989 of 119 countries using an augmented Solow model to explore institutional and regional factors affecting growth. Using a simple linear regression model, their findings concur with Barro's that both human capital and fertility are important.

Nonparametric methods use linear programming techniques to calculate TFP (Chavas and Cox, 1992). This approach was also proposed as an alternative to growth accounting during its hiatus, prior to the development of endogenous growth theory. It shares the advantage of the flexible econometric approach by not imposing assumptions about the technology that generates agricultural output (Capalbo and Vo, 1988). The methodology is discussed at length in chapter 2. Essentially, linear programming techniques are used to identify the input-output combinations that define the production frontier (technological efficiency) either over time and/or across countries. The method can be utilized with detailed micro-level data (Chavas and Aliber, 1993) or time series (Chavas and Cox. 1992). In the former, efficiency is the portion of output not explained by the inputs and is measured relative to the other operations in the data set. One can use it to calculate an index of technological (as well as economic) efficiency. The index can be used by itself for comparative purposes or as a dependent variable to examine what factors might affect technological efficiency.

All three methods have strengths and weaknesses. The use of index numbers imposes several strong assumptions about technology (Hicks-neutral technical change, constant returns to scale and long-run competitive equilibrium). Another disadvantage is that since index numbers are not statistically derived, statistical methods cannot be used to evaluate their reliability. Additionally, they have not been particularly informative in identifying sources of growth. Their advantage of course is that they can be derived regardless of the number of observations and hence they are relatively easy to calculate.

The econometric approach has the advantage of being statistical, hence permitting hypothesis testing and calculation of confidence intervals to test the reliability of the model estimated. This approach explicitly measures the marginal contribution of each category of inputs to aggregate agricultural output. If a flexible functional form is chosen, a further advantage is that fewer restrictive assumptions about technology are imposed; the flexible functional form provides a second order approximation to a general function (Antle and Capalbo, 1988). The major disadvantage of the econometric approach is that it requires more data than the other approaches. In many cases, the number of observations may not exist to permit this approach. Barro (1999) notes that directly estimating the change in TFP through econometric techniques involves problems of simultaneity, measurement error and time variation or dynamics of factor shares.

An advantage of the nonparametric approach is that it does not impose restrictive assumptions on production technology. Nor is it data intensive, hence it can be widely applied. The major disadvantage is that since the models are not statistical, they cannot be statistically tested or validated.

1.4 Factors influencing growth in agriculture

Economists originally limited themselves to examining the roles of labour and physical capital in economic growth. The failure to adequately explain growth led them to examine the roles of other factors and to develop endogenous growth theory. Investment in infrastructure has been cited as an important source of growth in agriculture (Jayne *et al.*, 1994). However, Ferreira and Khatami (1996) claim that economic literature has not reached a consensus on the direction of causality between infrastructure and development. Nor can investment be viewed in isolation of policy reform which has been shown to be a vital stimulus of production (Auraujo Bonjean, Chambas and Foirry, 1997; Lachaal, 1994; Lin, 1992; McMillan, Whalley and Zhu, 1989; Wiens, 1983); as have institutions (North, 1994). Public investment in forms of human capital: education, extension, training and technology research have also been shown to increase productivity (Antholt, 1994; Beal, 1978; Evenson and McKinsey, 1991; Pray and Evenson, 1991; Pardey, Roseboom and Craig, 1992; Rosegrant and Evenson, 1992).

Nelson (1964 and 1981) recognized that there are important interactions between capital formation, labour allocation, technical progress and productivity. This calls into question whether the growth due to physical capital can be separated from growth attributed to other inputs. Unless a production technology is a fixed Leontief process, there is always some degree of substitutability among categories of inputs. However, since inputs are not perfect substitutes, the lack of adequate investment can slow down production growth. Estimates of the elasticity of substitution in agriculture between hired labour and capital equipment vary from 0.32 in the short run (Brown and Christensen, 1981) to 1.78 percent (Lopez, 1980) in the long run.

Most measures of TFP incorporate inputs and physical capital, leaving human and social capital, technology, institutions, infrastructure and policy to "explain" growth in TFP. Social and human capital are the on-farm human elements that mediate how policy, technology, institutions and infrastructure affect input and physical capital use. Human capital directly affects whether and how technology will be adopted. Technology choice in turn, affects the inputs and physical capital used. That is, technology is embodied in the types of inputs and how they are used. Social capital affects access to physical capital (e.g. land directly or through land titling and loans) and variable inputs (e.g. through credit or cooperatives).

In general, researchers have estimated TFP and then focused on how one or several of these factors might be driving its growth (Antle, 1983; Nehru and Dhareshwar, 1994; Evenson and McKinsey, 1991; Rosegrant and Evenson, 1992). Usually, they have done so using the change in TFP as a dependent variable in a regression with explanatory variables that represent measures of technology, human capital and policy (which are not easily quantifiable or assignable in constructing the production indices). In the following sections, policy is divided between budgetary policies that affect investment in R&D and infrastructure, political and economic policies and political stability.

Human capital

Human capital directly influences agricultural productivity by affecting the way in which inputs are used and combined by farmers. Improvements in human capital affect acquisition, assimilation and implementation of information and technology. Human capital also affects one's ability to adapt technology to a particular situation or to changing needs.

Schultz's (1963) classic work attributed between 21 to 23 percent of the growth in U.S. income, between 1929 and 1957, to education of the labour force. Contemporaneously, Griliches (1963) focused on minimizing the unexplained portion of growth in U.S. agriculture by adjusting labour for quality, using education. When he included research and extension expenditure as an input to production, he found that virtually all the "unexplained" growth could be explained by economies of scale, R&D and labour quality changes. Romer (1986) and Lucas (1988) provide theoretical grounds for human capital being the driving force behind economic growth.

Jamison and Lau (1982) explored the role of farmer education and extension on farm efficiency. They found that farmer education and extension were not only important to enhancing production on Thai, Korean and Malaysian farms, but that there was an interaction effect between education and extension. In contrast, they found physical capital had an insignificant impact on production and profits. On the other hand, some researchers are finding evidence that returns to education are low, especially for those who stay in agriculture. In their summary of the findings on the determinants of rural poverty for six country studies based on econometrically estimated income equations, Lopez and Valdes (2000) conclude that the return to education in farming is surprisingly small in most cases. An increase in one year in the average level of schooling raises per capita annual income of the family by less than US$ 20 per person in most cases. The main contribution of education in rural areas appears to be to prepare young people to emigrate to urban areas and towns.

Using an econometric approach, Nehru and Dhareshwar (1994) examined sources of TFP growth in 83 industrial and developing countries for the period 1960-1990. They found that human capital formation was three to four times more important than raw labour in explaining output growth. Using human capital as a separate variable, they found that the countries with the fastest growing economies have based their growth on factor accumulation (human capital, labour and physical capital), not growth in efficiency or technology.

Research and technology transfer

Research increases the set of available technologies, hence agricultural R&D expenditures are used as a proxy for agricultural technological change. However, the development of technology does not always result in its adoption. In some cases this may be because the technology being developed is not appropriate, that is, it does not meet the needs of agricultural producers. Hence, researchers focus on public expenditure as an explanatory variable in TFP growth. Additionally public research has been shown to lead private research (Chavas and Cox, 1992).

Several caveats arise in focusing on public R&D to explain growth in agricultural TFP. Public R&D expenditures are used as proxy for R&D results, yet there is not an exact correspondence between expenditures and technology. Even when technology is produced, researchers may have different goals than farmers, e.g. yield maximization rather than profit maximization or risk minimization or improvement in commercial crops rather than staple crops. Additionally, when an appropriate technology does result, the process of technology adoption in agriculture is widely recognized as one that occurs over many years in which some adopt quickly and others wait for extension or the results of their neighbours to convince them to adopt.

Bearing this in mind, researchers have found that public investment in developing and extending agricultural technology is justified by the high rates of return to such investment. In a survey of studies on Asia, Pray and Evenson (1991) found rates of return to national research investment from 19 to 218 percent, returns to national extension investment from 15 to 215 percent and returns to international research investment of 68 to 108 percent. A report of the Taskforce on Research Innovations for Productivity and Sustainability indicated that the returns to research, though variable, were always high, from 22 to 191 percent. Using an index number approach to calculate TFP for several crops in India, Rosegrant and Evenson (1992) and Evenson and McKinsey (1991) used econometric analysis to identify sources of growth in TFP. Rosegrant and Evenson (1992) found that public research accounted for 30 percent of growth and extension for about 25 percent, with rates of return for each respectively of 63 percent and 52 percent. Evenson and McKinsey (1991) found that public investment in India in research accounts for over half of growth, while extension contributes about one-third and infrastructure accounted for very little growth. They calculated internal rates of return of 218 percent for public research, 177 percent for public extension and 95 percent for private research expenditures in India.

Block (1994) compares econometric estimates of TFP for Sub-Saharan Africa between 1963 and 1988. He uses three different methods of aggregating agricultural output: official exchange rates, purchasing power parity and wheat units. He finds that one-third of the growth in agricultural TFP in Sub-Saharan Africa is due to research expenditures. In India, Rao and Hanumantha (1994) attribute continued growth in agriculture, despite a sharp decline in physical capital formation, to better utilization of existing infrastructure, fertilizer and high yielding varieties.

While the returns to research are high, the technology is not always adopted. For example, high yield varieties (HYV) of wheat and rice have been introduced on less than one-third of the 423 million hectares planted to cereal grains in the Third World. Specifically, in Asia and the Middle East 36 percent of the grain area was HYV, 22 percent in Latin America and one percent in Africa (Wolf, 1987). This implies there is much potential for increasing agricultural productivity using existing technology. However, the use of HYV requires increased use of fertilizer, but external debt in Latin America and poverty and inadequate water supply in Africa have made fertilizer use and hence HYV unprofitable. Jahnke, Kirschke and Lagemann (n.d.) also attributed low adoption of HYV in Africa to lack of appropriate technology development and few extension services directed to women. Additionally, nontraditional crops have rarely been the focus of improved varieties or technology and potential exists to develop them to increase agricultural production.

Public investment and policy

Public policy and budgetary decisions regarding infrastructure also have a profound effect on agricultural production. The financing aspects of public R&D and human capital development were discussed above, but both physical and institutional infrastructure affect the development and transfer of technology. For example, irrigation systems and roads may be required to make a technology profitable to implement. Reforms in pricing policy or the marketing system may be needed to provide incentives.

A serious conflict arises with structural adjustment reforms. Budget cuts in public services often accompany market reforms. While fiscal restraint may be required to stabilize the economy in the short run, cuts in human capital development, public R&D, and infrastructure have a detrimental long-term effect on productivity growth. Policy makers need to choose carefully to mitigate the deleterious impacts of budget cuts on future growth.

Using an econometric approach, Jayne *et al*. (1994) demonstrated the complementarity of public policies and public investments in facilitating the use of new technology. They point to the sharp decline in public investments and growth in Zimbabwe during the 1980s. Pal (1985) underscores the complementarity of public policy towards investment in irrigation technology and private variable input use.

The importance of policy reform is increasingly viewed as fundamental for agricultural productivity gains. Liberalizing markets so prices can send proper signals to producers is the fundamental objective of structural adjustment programs in developing countries and policy reform in economies in transition. Assigning property rights is viewed as a means of promoting development through the efficient and responsible use of resources (North, 1994) and therefore underlies the distribution of capital in economies in transition, land reform and most land policy. Block (1994) discusses the complementarity of economic reform and technical change, but cautions that policy reform offers a one-time effect.

An example of the relation between policy reform and productivity is the implementation of China's "responsibility system" (RS) in 1980-81, which linked productivity to material reward, resulted in increased crop yields "for every major crop" (Wiens, 1983). McMillan, Whalley and Zhu (1989) calculated that in response to the RS and price reforms, output in the Chinese agricultural sector increased by over 61 percent between 1978 and 1984. They attribute 78 percent of the increase to the RS and 22 percent to higher prices for crops. They calculate the RS increased productivity in agriculture by 32 percent. Lin (1992) calculated that 42 to 47 percent of the growth in agricultural output was attributable to the RS during the same period.

In another example, price reforms in Egypt implemented in 1986 resulted in increased wheat and maize yields from 1987 to 1993. Rice production increased by 62 percent, while yields increased by 42 percent (Khedr, Ehrich and Fletcher, 1996). Bevan, Collier and Gunning (1993) contrast the performance of agriculture in Kenya and Tanzania. In Kenya where there was little intervention production of food and cash crops increased by 4.6 and 5.5 percent per annum, respectively. In Tanzania, where policies controlled prices and taxed export crops, agricultural production stagnated until policy reforms were instituted in 1984.

Using an econometric approach to estimate TFP for the United States dairy industry 1972-1992, Lachaal (1994) examined how protectionist policies in the form of direct subsidies to agriculture reduced productivity growth in the United States dairy industry. Lachaal showed that government subsidies encouraged using materials at the expense of feed and raised the cost of production by 1.8 percent for each 10 percent increase in subsidy. The subsidy policy was the source of technical inefficiency, creating biases that distorted factor usage.

Political stability and conflict

Another aspect of policy that can influence or hinder agricultural production is the political situation. In a study of the productivity growth of 83 industrial and developing countries between 1960 and 1990, Nehru and Dhareshwar (1994) found that the economies that perform the worst are those involved in wars (particularly civil wars) and those that have the most price distorting policies. They explore a variety of policy variables and find that apart from political stability and the initial endowments of a county, virtually no other policy variable is associated with growth.

The World Food Summit Plan of Action items 2 and 3 (1996b) recognize the role of government in providing an environment conducive to investment, through guarantee of rights and law as well as policies encouraging investment. Corruption is the extreme case where law enforcement breaks down and incentives are lacking. While long-standing institutionalized bribery can be seen as simply an added cost of doing business, pervasive corruption and violence increase risk and result in capital flight, disinvestment and jeopardize assistance.

1.5 Data needs for growth models

In order to estimate any type of growth model, data are needed on agricultural output and inputs, including capital and labour. Comparable and consistent data are needed to make cross-country comparisons over time and space. The FAOSTAT under the World Agricultural Information Centre (WAICENT) is one of the most comprehensive agricultural databases created by FAO. FAOSTAT data are available by country and by year on agricultural production (crop and livestock), trade, land, economically active population in agricultural activity and means of production. The data on means of production include details of agricultural tractors, harvesters and threshers and milking machines in use, trade (export and import) portion of other agricultural machinery, fertilizers and pesticides. These data are generally expressed in quantity except for data on agricultural production and trade, which are in value.

FAOSTAT database does not include any data on structures, hand tools and value of improvements to land. The System of Economic Accounts for Food and Agriculture (SEAFA) (FAO, 1996) represents guidelines for the creation of a comprehensive database of physical capital for use of FAO member countries. SEAFA is a specific application of the United Nations 1993 System of National Accounts (SNA). The UN Statistics Division, jointly with the OECD, will be collecting data on national accounts aggregates based on 1993 SNA from member countries, starting in 2000. These data will include fixed gross capital formation in agriculture.

Gross fixed capital formation under SEAFA will include: 1) acquisitions less disposal of farm buildings and other structures, machinery and equipment, plantations, trees and livestock that can be used repeatedly or continually to produce fruit, rubber or milk; 2) improvements to tangible assets including land; and 3) costs associated with the transfer of ownership of non-produced assets. Gross fixed capital formation specifically includes breeding stock, dairy cattle, sheep reared for wool and draught animals. Land improvements include reclamation of land by construction of dams, dikes or walls, drainage of marshes and flood control. Thus, SEAFA represents a vast improvement in the database on physical capital.

However, time series on gross fixed capital formation are not based on primary data collected in the field. Benchmark estimates of farm assets are extrapolated using quantity and price indices. Consumption of fixed capital is based on estimated useful life and estimated current value of the stock of fixed assets.

Data issues

Regardless of the source of data, there are several data issues that are widely recognized in estimating growth models. Each is discussed below to highlight the importance and difficulty of developing consistent international data standards. However, developing data standards that will be in place a long time facilitate future researchers' ability to analyse and explain trends.

Aggregation

Griliches (1987) definition of productivity, "a ratio of some measure of output to some index of input use," highlights the vagaries of aggregating outputs and inputs. The physical units are simply not interchangeable unless converted to some common physical equivalent (Block, 1994). However, monetary values are the most widely used method of aggregating both inputs and outputs, since monetary values can be summed together in a meaningful way and prices reflect the relative value of the items being aggregated.

Exchange rates

In order to do cross country comparisons over time, data must be converted to a common real unit (i.e. adjusted for currency differences and inflation). However, an extensive literature outlines the problems associated with using official exchange rates to convert values to a common unit (Antle, 1983; Block, 1994; Nehru and Dhareshwar, 1994; and Pardey, Roseboom and Craig, 1992). The argument is that official exchange rates that do not reflect the actual currency values distort relative price relations. Purchasing power parity (PPP) has been used as an alternative (Pardey, Roseboom and Craig, 1992). However, Antle (1983) argues that PPP has little relevance to agricultural output because it is based largely on non-agricultural goods and services and their use overstates agricultural production in developing countries. Another technique to avoid exchange rate distortions is to convert production to a common physical unit, such as "wheat units" (Block, 1994). Summers and Heston (1988) provide recommendations and develop a System of Real National Accounts that permits cross country comparisons.

Disaggregation

Insufficient disaggregation of inputs implies the inability to assign inputs to particular outputs. For example, the total amount of fertilizer or labour may be known, but how they are allocated among agricultural products may not. This is of particular importance when allocation of inputs is skewed to a minority of producers or crops such that reallocation could greatly improve total agricultural output.

Perhaps a greater problem exists with public expenditures and how to allocate them to agriculture. Rural development projects, for example, may have an agricultural component, but may not have an exclusively agricultural focus. Public education and training is rarely exclusively for agriculture, creating problems of how to allocate the expenditures to agriculture. Private education and training investments also are difficult to separate out an agricultural component.

Measuring inputs and outputs

A well-recognized problem is simply in measuring output. Kelly *et al*. (1995) estimate that data collection methods underestimate African agricultural production by up to 50 percent. This is because mixed cropping is common, crop by-products are not enumerated, crops are consumed at home or as inputs to other household production activities, or farmers have diversified into new products that are poorly enumerated in national surveys. On the input side, little data is available on small capital investments such as implements and land improvements, especially the value of family labour in land improvements.

Valuing natural and human resources

Neither technology nor human capital can be quantified directly. Expenditures on research and extension have been successfully used as proxies for technology. Proxies for human capital are more problematic. Education level is generally available only at the national or regional level, not for the agricultural sector, thus is only a rough estimate of the level of agricultural human capital.

Measuring social capital generally requires a micro-data collection to develop a proxy. In village level studies, group affiliation or status has been used. At the country level, an aggregate proxy may be difficult to implement. One possibility is to use the percent of farms that are headed by males. Rural household income could be used as a proxy for relative wealth or status.

In official statistics, neither the value of natural resources nor the cost of environmental degradation are recognized in valuing land (FAO, 1996, p. 49). Wolman (1985) estimates that ignoring these costs can be high. He reports agricultural productivity losses due to soil erosion up to 40 percent in the former USSR, 25 percent in the US, 30 percent in Haiti and 25 percent in Nigeria.

Lag length and dynamics of investments

Another issue that affects data requirements, is exploring the time lag over which investments affect productivity. Capital investments by definition affect production in more than one year. The contribution of capital items to production diminishes or depreciates over time. In some cases the process may be linear, but in others the trajectory may be quite nonlinear or even discontinuous. Additionally, the process may be quite long. Chavas and Cox (1992) found that 30 years are required to fully capture the effects of public research expenditures in US agricultural productivity. This implies the need for extensive time series data to measure the effects of investments on productivity.

1.6 Summary and conclusions

This paper has surveyed a number of issues relating to different aspects of agricultural investment, agricultural productivity and its determinants. Economic research indicates that the investigation of the relationship between agricultural investment and productivity requires updating the working definition of investment and extending it beyond physical capital. Researchers have found a relatively weak relationship between physical capital and growth, as compared to investment in technology and human capital. Nonetheless, physical capital investments may be the precursor that stimulates private investment and it is complementary to public and private investments in human capital. Other factors that are important stimulants or inhibitors to growth include: the policy environment, political stability and natural resource degradation. Evaluating the importance of the latter runs into problems of lack of data on the value of natural resources and the cost of their depletion and degradation.

Furthermore, this paper provides background on methodologies used in the rest of the book. It presents the advantages and the drawbacks of the different approaches that have been used to measure agricultural productivity. Some of the main data issues related to estimating growth models were identified and the importance and difficulty of developing consistent international data has been highlighted. In fact, the existence of consistent data over time will facilitate future researchers' ability to analyze and explain trends. FAOSTAT, under the World Agricultural Information Centre (WAICENT), and the UN Statistics Division, jointly with OECD, are operating along these lines to develop a comprehensive and consistent dataset of fixed capital formation in 170 countries.

References

Abramovitz, M. 1956. Resource and output trends in the United States since 1870. *American Economic Review, Papers and Proceedings,* 46 May: 5-23.

Ahearn, M., Yee, J., Ball, E. & Nehring, R. 1998. Agricultural productivity in the United States. Resource Economics Division, Economic Research Service, U.S. Department of Agriculture. Agriculture Information Bulletin no. 740.

Antholt, C.H. 1994. Getting ready for the twenty-first century: technical change and institutional modernization in agriculture. World Bank Technical Paper #217. February.

Antle, J. 1983. Infrastructure and aggregate agricultural productivity: international evidence. *Economic Development and Cultural Change,* 31 April: 609-619.

Antle, J. & Capalbo, S. 1988. An introduction to recent developments in production theory and productivity measurement. In S. Capalbo & J. Antle, eds. *Agricultural productivity measurement and explanation.* Washington, DC, Resources for the Future, pp17-95.

Auraujo Bonjean, C., Chambas, G. & Foirry, J.P. 1997. Consequences de l'ajustement des finances publiques sur l'agriculture marocaine et tunisienne. Unpublished FAO study, March.

Barro, R. 1991. Economic growth in a cross-section of countries. *Quarterly Journal of Economics,* 106 (2): 407-444.

Barro, R. 1999. Notes on growth accounting. *Journal of Economic Growth,* 4 June: 119-137.

Beal, D.W. 1978. Agricultural education and training in developing countries. In *FAO Studies in Agricultural Economics and Statistics, 1952-1977*. Rome, FAO, pp. 282-291.

Bevan, D., Collier, P. & Gunning, W. 1993. Government policies and agricultural performance: Tanzania and Kenya. In I. Goldin, ed. *Economic reform, trade and agricultural development.* Paris, OECD.

Block, S. 1994. A new view of agricultural productivity in Sub-Saharan Africa. *American Journal of Agricultural Economics,* 76 August: 619-624.

Bosworth, B. 1982. Capital formation and economic policy. *Brookings Papers on Economic Activity,* 2: 273-317.

Brown, R.S. & Christensen, L.R. 1981. Estimating elasticities of substitution in a model of partial static equilibrium: an application to US agriculture, 1947-74. In E. Berndt & B. Fields, eds. *Modeling and measuring natural resource substitution.* Cambridge, USA, MIT Press.

Capalbo, S. 1988. A comparison of econometric models of US agricultural productivity and aggregate technology. In S. Capalbo & J. Antle, eds. *Agricultural productivity measurement and explanation.* Washington, DC, Resources for the Future, pp. 159-188.

Capalbo, S. & Vo, T. 1988. A review of evidence on agricultural productivity and aggregate technology. In S. Capalbo & J. Antle, eds. *Agricultural productivity measurement and explanation.* Washington, DC, Resources for the Future, pp. 96-137.

Chavas, J.P. & Aliber, M. 1993. An analysis of economic efficiency in agriculture: a nonparametric approach. *Journal of Agricultural and Resource Economic,* 18(1): 1-16.

Chavas, J.P. & Cox, T. 1992. A nonparametric analysis of the influence of research on agricultural productivity. *American Journal of Agricultural Economics,* 74: 583-591.

Coen, R.M. & Eisner, R. 1987. Investment. In J. Eatwell, M. Milgate & P. Newman, eds. *The new Palgrave dictionary of economics*, *vol 2*. New York, USA, Stockson Press.

Cornwall, J. 1987. Total factor productivity. In J. Eatwell, M. Milgate & P. Newman, eds. *The new Palgrave dictionary of economics*, *vol 4*. New York, USA, Stockson Press.

Denison, E. 1967. *Why growth rates differ: postwar experience in nine western countries*. Washington,DC, Brookings.

Denison, E. 1987. Growth accounting. In J. Eatwell, M. Milgate & P. Newman, eds. *The new Palgrave dictionary of economics*, *vol 2*. New York, USA, Stockson Press.

Diewert, W.E. 1976. Exact and superlative index numbers. *Journal of Econometrics,* 4: 115-145.

Diewert, W.E. 1980. Capital and the theory of productivity measurement. *American Economic Review,* 70: 260-267.

Diewert, W.E. 1981. The economic theory of index numbers: a survey. In A. Deaton, ed. *Essays in the theory and measurement of consumer behaviour in honour of Sir Richard Stone.* London, Cambridge University Press.

Dixit, A.K. & Pindyck, R.S. 1994. *Investment under uncertainty*. Princeton, USA, Princeton University Press.

Eisner, R. 1985. The total incomes system of accounts. *Survey of Current Business,* 56 January: 24-48.

Evenson, R.E. & McKinsey Jr., J.W. 1991. Research, extension, infrastructure and productivity change in Indian agriculture. In R.E. Evenson & C.E. Pray, eds. *Research and productivity in Asian agriculture.* Ithaca, USA, Cornell University Press.

Feder, G., Just, R.E. & Zilberman, D. 1985. Adoption of agricultural innovations in developing countries: a survey. *Economic Development and Cultural Change,* 33: 255-298.

Ferreira, D. & Khatami, K. 1996. Financing private infrastructure in developing countries. World Bank Discussion Paper # 343 December. Washington, DC, World Bank.

Food and Agriculture Organization. 1996. *A system of economic accounts for food and agriculture*. FAO Statistical Development Series, 8. Rome, FAO.

Griliches, Z. 1963. The sources of measured productivity growth: United States agriculture, 1940-1960. *Journal of Political Economic,* 71(4): 331-346.

Griliches, Z. 1987. Productivity: measurement problems. In J. Eatwell, M. Milgate & P. Newman, eds. *The new Palgrave dictionary of economics*, *vol 3*. New York, USA, Stockson Press.

Hayami, Y. & Ruttan, V.W. 1985. *Agricultural development: an international perspective.* Baltimore, USA, Johns Hopkins University Press.

Hsieh, C.T. 1998. What explains the industrial revolution in East Asia? Evidence from factor markets. Unpublished paper, University of California, Berkeley, USA, January.

International Monetary Fund. 1995. *Government finance statistics yearbook.* Washington, DC, IMF.

Jahnke, H. E., Kirschke, D. & Lagemann, J. n.d. The impact of agricultural research in tropical Africa: a study of the collaboration between international and national research systems. CGIAR Study Paper Number 21. Washington, DC, World Bank.

Jamison D. & Lau, L. 1982. *Farmer education and farm efficiency.* Washington, DC, World Bank.

Jayne, T.S., Khatri, Y., Thirtle, C. & Reardon, T. 1994. Determinants of productivity change using a profit function: smallholder agriculture in Zimbabwe. *American Journal of Agricultural Economics,* 76 August: 613-618.

Judd, M.A., Boyce, J.K. & Evenson, R.E. 1991. Investment in agricultural research and extension programs: a quantitative assessment. In R.E. Evenson & C.E. Pray, eds. *Research and productivity in Asian agriculture.* Ithaca, USA, Cornell University Press.

Kelly, V., Hopkins, J., Reardon, T. & Crawford, E. 1995. Improving the measurement and analysis of African agricultural productivity: promoting complementarities between micro and macro data. Michigan State University International Development Paper No. 16. East Lansing, USA, Department of Agricultural Economics.

Kendrick, J. 1973. *Postwar productivity trends in the United States, 1948-1969*. New York, USA, National Bureau of Economic Research.

Kerf, M. & Smith, W. 1996. Privatizing Africa's infrastructure. World Bank Technical Paper no. 337, September. Washington, DC, World Bank.

Khedr, H., Ehrich, R. & Fletcher, L.B. 1996. Nature, rationale and accomplishments of the agricultural policy reforms, 1987-1994. In L.B. Fletcher, ed. *Egypt's agriculture in a reform era.* Ames, USA, Iowa State University Press.

Lachaal, L. 1994. Subsidies, endogenous technical efficiency and the measurement of production growth. *Journal of Agriculture and Applied Economics,* 26(1): 299-310.

Levine, R. & Renelt, D. 1992. A sensitivity analysis of cross-country growth regressions. *American Economic Review,* 82(4) : 942-963.

Lin, J.Y. 1992. Rural reforms and agricultural growth in China. *American Economic Review,* 82 March: 34-51.

Lopez, R. & Valdes, A. 2000. *Rural poverty in Latin America: Analytics, new empirical evidence, and policy.* London: Macmillan Press. Forthcoming.

Lopez, R. 1980. The structure of production and the derived demand for inputs in Canadian agriculture. *American Journal of Agricultural Economics,* 62(1): 38-45.

Lucas, R. 1988. On the mechanics of economic development. *Journal of Monetary Economics* 22: 3-42.

Mankiw, N.G., Romer, D. & Weil, D.N. 1992. A contribution to the empirics of economic growth. *Quarterly Journal of Economics,* 107(2): 407-437.

McMillan, J., Whalley, J. & Zhu, L. 1989. The impact of China's economic reforms on agricultural productivity growth. *Journal of Political Economy,* 97 August: 781-807.

Metcalfe, S. 1987. Technical change. In J. Eatwell, M. Milgate & P. Newman, eds. *The new Palgrave dictionary of economics*, *vol 4*. New York, USA, Stockson Press.

Nehru, V. & Dhareshwar, A. 1994. New estimates of total factor productivity growth for developing and industrial countries. World Bank Policy Research Working Paper #1313, June. Washington, DC, World Bank.

Nelson, C. H., Braden, J.B. & Roh, J.S. 1989. Asset fixity and investment asymmetry in agriculture. *American Journal of Agricultural Economics,* 71November: 970-979.

Nelson, R. 1964. Aggregate production functions and medium-range growth projections. *American Economic Review,* 54(5): 575-606.

Nelson, R. 1981. Research on productivity growth and productivity differences: dead ends and new departures. *Journal of Economic Literature,* 19(3): 1029-1064.

North, D. 1994. Economic performance through time. *American Economic Review,* 84(3): 359-368.

Pal, S.P., ed. 1985. *Contribution of irrigation to agricultural production and productivity.* New Dehli, National Council of Applied Economic Research.

Pardey, P.G., Roseboom, J. & Craig, B.J. 1992. A yardstick for international comparisons: an application to national agricultural research expenditures. *Economic Development and Cultural Change,* 40: 333-349.

Pray, C.E. & Evenson, R.E. 1991. Research effectiveness and the support base for national and international agricultural research and extension programs. In R.E. Evenson & C.E. Pray, eds. *Research and productivity in Asian agriculture.* Ithaca, USA, Cornell University Press.

Rahm, M.R. & Huffman, W.E. 1984. The adoption of reduced tillage: the role of human capital and other variables. *American Journal of Agricultural Economics,* 66: 405-413.

Rao, C. & Hanumantha, H. 1994. *Agricultural growth, rural poverty and environmental degradation in India*. New Dehli: Oxford University Press.

Rao, D.S.P. 1993. Intercountry comparisons of agricultural output and productivity. FAO Economic and Social Development Paper 112. Rome, FAO.

Rogers, E. & Stanfield, J.D. 1968. Adoption and diffusion of new products: emerging generalizations and hypotheses. In F.M. Bass, C.W. King & E.A. Pessemier eds. *Application of the sciences in marketing management.* New York, USA, John Wiley & Sons.

Romer, P. 1986. Increasing returns and long run growth. *Journal of Political Economic,* 94: 1002-1037.

Romer, P. 1990. Endogenous technological change. *Journal of Political Economic,* 98 part II: S71-S102.

Rosegrant, M.W. & Evenson, R.E. 1992. Agricultural productivity and sources of growth in South Asia. *American Journal of Agricultural Economics,* 74 August: 757-761.

Rosenzweig, M.R. & Binswanger, H.P. 1993. Wealth, weather risk and the composition and profitability of agricultural investment. *The Economic Journal,* 103 January: 56-78.

Schultz, T.W. 1963. *The economic value of education*. New York, USA, Columbia University Press.

Solow, R. 1957. Technical change and the aggregate production function. *Review of Economics and Statistics,* 39 August: 312-320.

Summers, R. & Heston, A. 1988. A new set of international comparisons of real product and price levels estimates for 130 countries 1950-1985. *The Review of Income and Wealth,* 34(1): 1-25.

Taskforce on Research Innovation for Productivity and Sustainability. n.d. Global research on the environmental and agricultural nexus for the 21st century: a proposal for collaborative research among US universities, CGIAR centers and developing country institutions. Gainesville, USA, Office of International Studies and Programs at the University of Florida.

Wiens, T.B. 1983. Price adjustment, the responsibility system and agricultural productivity. *American Economic Review, papers and proceedings,* 73 May: 319-324.

Wolf, E.C. 1987. Raising agricultural productivity. In *State of the world: a Worldwatch Institute report on progress toward a sustainable society*. Worldwatch, pp. 139-156.

Wolman, M.G. 1985. Soil erosion and crop productivity: a worldwide perspective. In R.F. Follett & B.A. Stewart, eds. *Soil Erosion and Crop Productivity.* Madison, USA, American Society of Agronomy.

World Food Summit. 1996a. Technical background documents 1-15. Rome, FAO.

World Food Summit. 1996b. Plan of Action. Rome, FAO, 13-17 November.

Wozniak, G.D. 1989. The adoption of interrelated innovations: a human capital approach. *Review of Economics and Statistics,* 66: 70-79.

2. An international analysis of agricultural productivity

Jean-Paul Chavas

The paper provides an international analysis of agricultural productivity. It relies on non-parametric methods to estimate a representation of technology. The analysis uses FAO annual data on agricultural inputs and outputs for 12 countries between 1960 and 1994. Productivity indexes are estimated using non-parametric methods. They show the evolution of agricultural productivity both over time and across countries. The empirical results illustrate the usefulness of the methodology as well as the limitations of current data.

2.1 Introduction

Much interest has focused on the international analysis of agricultural productivity. Differences in agro-climatic conditions, human capital and infrastructure appear to contribute to a spread in agricultural productivity across countries. Following an early cross-country analysis by Bhattaccharjee (1995), a significant impetus in understanding the factors influencing international agricultural productivity was provided by Hayami (1969, 1970) and Hayami and Ruttan (1970), with updating by Nguyen (1979), Kawagoe and Hayami (1983), and Kawagoe, Hayami and Ruttan (1985). They stressed the influence of education and human capital on productivity growth. By conducting a separate analysis for developed countries and developing countries, Hayami and Ruttan (1970) implicitly assumed that technology may change with the level of development. This raises the question of how agricultural productivity varies across countries. In an attempt to explain cross-country differences in agricultural productivity, Evenson and Kislev (1975) emphasized the role of research, while Antle (1983) focused on the influence of infrastructure. These studies used econometric analyses relying on a Cobb-Douglas production function. They all faced both measurement problems (e.g. some variables are not consistently measured across countries) and multicollinearity problems that prevented a precise estimate of some parameters. In a recent survey of this literature, Mundlak (forthcoming) noted some significant differences in the empirical findings across studies. He concludes that previous research "provide clear evidence for the lack of robustness of the empirical results". One possible explanation may be the restrictive nature of the Cobb-Douglas production function. It is now well known that the Cobb-Douglas form is not "flexible" in the sense that it restricts *a priori* the Allen elasticities of substitution among inputs to be equal to one (Arrow *et al.,* 1961). This suggests using more flexible functional forms. Another possibility may be that the production function varies across countries in ways that are more complex than acknowledged in the literature (Mundlak and Hellinghausen, 1982). Finally, it may be that data quality and measurement problems have adverse effects on the reliability of the empirical results.

In an attempt to develop more flexible analyses of production issues, two approaches have been proposed in the literature: the flexible parametric approach, and the non-parametric approach. The flexible parametric approach relies on a flexible parametric specification of the production function, cost function or profit function (Forsund, Lovell and Schmidt, 1980; Bauer, 1990). A parametric form is said to be flexible if it does not impose *a priori* restrictions on the Allen elasticities of substitution among inputs. For example, the translog specification proposed by Christensen and Jorgenson (1970) is "flexible" and has been commonly used in econometric analyses of production issues over the last two decades. The flexible parametric approach provides a consistent framework for investigating econometrically technology, production behaviour, and productivity growth. However, it still requires imposing parametric restrictions on the technology underlying production behaviour (Bauer, 1990). Alternatively, the non-parametric approach has been developed following the work of Afriat (1972), Hanoch and Rothschild (1972), Diewert and Parkan (1983), and Varian (1984). It has the advantage of imposing no *a priori* restriction on the underlying technology (Seiford and Thrall, 1990; Fare *et al.*, 1985).

This research develops a non-parametric approach to production analysis to investigate international agricultural productivity. The analysis develops productivity indexes based on Shephard's (1970) input distance function and non-parametric representation of technology. The approach is applied to FAO annual data of inputs and outputs for twelve countries for the period 1960-1994. This illustrates the usefulness of the non-parametric approach in analysing and understanding international agricultural productivity. It also illustrates the complexity of measurement issues in productivity analysis, and the importance of data quality.

The paper is organized as follows. Section 2.2 reviews some basic concepts of production theory, relying on Shephard's distance function. It presents technical efficiency indexes that can be used to characterize the rate of technical change and productivity growth. In a first step toward the non-parametric estimation of these indexes, section 2.3 summarizes some results obtained by Afriat (1972) and Varian (1984) on non-parametric production analysis. Given a finite number of observations on production data, a key result is the derivation of representations of the underlying technology. Section 2.4 illustrates the usefulness of non-parametric methods in an application to international agricultural productivity analysis. The analysis relies on time-series cross-section data and generates non-parametric estimates of indexes providing information on the importance and nature of technical change and productivity growth in international agriculture over the last few decades.

2.2 Methodology

This section briefly presents and reviews some index numbers that are useful in productivity analysis. It also sets up the notation for the rest of the paper. Consider a competitive firm choosing (x, y) where $x = (x_1, ..., x_n)' \geq 0$ is a $(n\times 1)$ vector of inputs and $y = (y_1, ..., y_m)' \geq 0$ is a $(m\times 1)$ vector of outputs. Using the netput notation (where outputs are positive and inputs are negative), the corresponding netput vector is $(-x, y)$. Focus is on a general multi-output multi-input joint technology represented by the feasible set $F \subset R_-^n \times R_+^m$, where $(-x, y) \in F$. We assume throughout the paper that the production set F is non-empty, closed, convex, and negative monotonic.[1]

Given some input-output vector (x, y), the technology F can be characterized by Shephard's input distance function:

$$D(x, y, F) = \max_\gamma \{\gamma: (-x/\gamma, y) \in F, \gamma \in R_+\} \tag{2.1}$$

Assuming that the maximization problem in 2.1 has a solution, the distance function involves a proportional rescaling of inputs x toward the frontier technology. Shephard (1970) has shown how the distance function $D(x, y, F)$ characterizes the production technology. $D(x, y, F)$ is

[1] The set F is said to be negative monotonic if $z \in F$ and $z' \leq z$ implies that $z' \in F$. That is basically a "free disposal" assumption.

linearly homogeneous in x, non-decreasing in x, and non-increasing in y. It has the following interpretations. First, $(-x, y) \in F$ if and only if $D(x, y, F) \geq 1$ (Shephard, p. 67). Second, $D = 1$ implies that the inputs-outputs vector (x, y) is on the production frontier associated with the technology F, while $D > 1$ (< 1) implies that the inputs-outputs (x, y) are below (above) the production frontier (Shephard, p. 67). As such, $D(x, y, F) = 1$ can be used as a representation of the multi-input, multi-output production frontier associated with technology F. And as long as D is finite, the outputs-inputs vector $(x/D, y)$ is on the production frontier of technology F, where (x/D) is the $(n \times 1)$ vector of input quantities x "radially rescaled" toward the production frontier.

Following the work of Debreu (1951), Farrell (1957), Farrell and Fieldhouse (1962) and Fare *et al.* (1985), technical efficiency can be defined as the minimal proportion by which a vector of inputs x can be rescaled while still producing outputs y. It follows that the distance function D in 2.1 can be used to define the following Farrell technical efficiency index

$$T(x, y, F) = 1/D(x, y, F). \tag{2.2}$$

The technical efficiency index T satisfies $(-x, y) \in F$ if and only if $T(x, y, F) \leq 1$. Also, $T(x, y, F)$ is homogeneous of degree (-1) in x, non-increasing in x, and non-decreasing in y. Moreover, $T = 1$ implies that the output-input vector (x, y) is on the production frontier of technology F, while $T < 1$ (> 1) means that the outputs-inputs are below (above) the production frontier. Then $(x \cdot T)$ is the $(n \times 1)$ vector of inputs quantities x that are radially rescaled toward the production frontier. Finding $T = 1$ identifies a situation of technical efficiency, where inputs-outputs (x, y) are on the production frontier. Alternatively, finding $T < 1$ identifies a situation of technical inefficiency where inputs-outputs (x, y) are below the production frontier. The technical inefficiency is motivated by the fact that, under technology F, the outputs y could have been produced by using less inputs x. In this context, $(1 - T)$ can be interpreted as measuring the proportional reduction in all inputs x that could have been attained producing outputs y in a technically efficient way (given a radial reduction in inputs from x toward the production frontier). Alternatively stated, letting r be the $(n \times 1)$ vector of input prices for x, $(1 - T)$ measures the proportional reduction in input cost $r'x$ that could have been obtained by becoming technically efficient in the production of outputs y. Finally, finding $T > 1$ identifies a situation of "super technical efficiency" where inputs-outputs (x, y) are above the production frontier under technology T. Since technical feasibility is equivalent to $T(x, y, F) \leq 1$, such a case is possible only under technological change. For example, this would correspond to a situation where inputs-outputs (x, y) are chosen under a technology F' that is better than technology F in the sense that $(-x, y) \in F' \supset F$.

The input distance function D in 2.1 or the technical efficiency index T in 2.2 can be used to define productivity indexes. For that purpose, consider two situations: situation (a) corresponding to inputs-outputs (x^a, y^a) under technology F^a, and situation (b) corresponding to inputs-outputs (x^b, y^b) under technology F^b. Then, technological change between (a) and (b) can be measured using the following two productivity indexes

$$P(a, b) = D(x^a, y^a, F^a)/D(x^b, y^b, F^a) = T(x^b, y^b, F^a)/T(x^a, y^a, F^a) \tag{2.3a}$$

and

$$P'(a, b) = D(x^b, y^b, F^b)/D(x^b, y^b, F^a) = T(x^b, y^b, F^a)/T(x^b, y^b, F^b). \tag{2.3b}$$

Both productivity indexes 2.3a and 2.3b are ratios of distance functions D, or equivalently of technical efficiency indexes T. The index $P(a, b)$ in 2.3a is the Malmquist productivity index proposed by Caves *et al.* (1982): it is the ratio of two distance functions evaluated under the same technology F^a, but at different points (x^a, y^a) and (x^b, y^b). Alternatively, the index $P'(a, b)$

in 2.3b is the ratio of two distance functions evaluated at the same point (x^b, y^b), but under the different technologies F^a and F^b. The index P' measures productivity in the sense that $P' > 1$ for all (x^b, y^b) implies that $F^a \subset F^b$, meaning that technology F^b is better than technology F^a in the sense that the feasible set has expanded between situation (a) and situation (b). When (a) and (b) denote different time periods, this means that technological progress has taken place between time (a) and time (b). Then, $(PI' - 1)$ can be interpreted as a measure of the rate of technological change. It reflects the proportional reduction in all inputs x (or in input cost $r'x$) that could have been attained producing outputs y using technology F^b instead of F^a (given a radial reduction in inputs from x toward the shifting production frontier).

In general, the two productivity indexes P in 2.3a and P'in 2.3b differ from each other. However, a special case of interest has been considered by Caves *et al.* (1982). It involves situations where the observed inputs-outputs (x^a, y^a) and (x^b, y^b) are always on the production frontier. In such cases, $D(x^a, y^a, F^a) = 1 = T(x^a, y^a, F^a)$ and $D(x^b, y^b, F^b) = 1 = T(x^b, y^b, F^b)$. It follows that

$$P = P' = 1/D(x^b, y^b, F^a) = T(x^b, y^b, F^a). \tag{3c}$$

This means that the two productivity indexes P and P' become identical, and productivity can be measured by the technical efficiency index T evaluated at (x^b, y^b) under technology F^a. Finding $P = P' = 1$ would mean that switching between technology F^a and F^b generates no technical efficiency gain, and no productivity growth. Alternatively, finding $P = P' > 1$ for all (x, y) would imply that technology F^b is better than technology F^a in the sense that $F^b \supset F^a$. In the case where $P > 1$, $(P - 1)$ is a measure of productivity growth between (a) and (b). It gives the proportional increase in inputs x^b that would be required to produce outputs y^b using technology F^a instead of F^b (given a radial rescaling of inputs x^b toward the shifting frontier isoquant). Alternatively, letting r be a $(n\times 1)$ vector of input prices for x^b, $(P - 1)$ measures the proportional increase in cost $r'x^b$ that would be needed to produce y^b using technology F^a instead of F^b. And in the case where $P < 1$, $(1 - P)$ is a measure of productivity growth between (b) and (a). It is the proportional decrease in inputs x^b (or in input cost $r'x^b$) that could be obtained in a technically efficient production of outputs y^b using technology F^a instead of F^b (given a radial rescaling of inputs x^b toward the shifting frontier isoquant).

Note that alternative indexes have been discussed in the literature. For example, indexes similar to 2.1, 2.2 and 2.3 can be obtained by rescaling outputs instead of inputs (Shephard, 1970; Fare *et al*., 1985; Caves *et al.*, 1982). Also, indexes that rescale both inputs and outputs have been proposed (Fare *et al.*, 1985). In general, input-based indexes can differ from output-based indexes (Caves *et al.*, 1982; Fare *et al.*, 1985). The difference relates to the nature of returns to scale (Caves *et al.,* 1982). So far, we have considered a general variable-return-to-scale (VRTS) technology F. This suggests that we also consider the constant-return-to-scale (CRTS) technology

$$F_c = \{(x, y): (-\gamma x, \gamma y) \in F, \text{ for some } \gamma > 0\} \tag{2.4}$$

The technology F_c generated by F in 2.4 is the smallest CRTS technology that contains F. It satisfies $F \subseteq F_c$. The CRTS technology F_c has an interesting property. As shown by Caves *et al.* (1982) and Fare *et al.* (1985), under a CRTS technology, input-based and output-based technical efficiency indexes as well as productivity indexes are identical. In this case, the technical efficiency index $T(x, y, F_c)$ can be interpreted as the largest scalar δ satisfying $(-x, \delta \cdot y) \in F_c$. Then, if $T(x, y, F_c) > 1$, $(T - 1)$ measures the proportional increase in outputs y that could have been obtained using inputs x under technology F_c. And if $T(x, y, F_c) < 1$, $(1 - T)$ is the proportional decrease in outputs y that would be generated by using inputs x under technology F_c.

In the context of (3c) where $P = P' = T(x^b, y^b, F_c^{\,a})$, finding $P = P' > 1$ under CRTS means that $(P - 1)$ gives the proportional decrease in outputs y^b that would be required using inputs x^b under technology F^a instead of F^b (given a radial rescaling of outputs y^b toward the shifting production frontier). Alternatively, letting p be a $(m\times 1)$ vector of output prices for y, $(P - 1)$ measures the proportional reduction in revenue $p'y^b$ that would be generated by using inputs x^b under technology F^a instead of F^b. And finding $P = P' < 1$ under CRTS implies that $(1 - P)$ is the proportional increase in outputs y^b (or in revenue $p'y^b$) that can be obtained by using inputs x^b under technology F^a instead of F^b. This is consistent with the intuitive interpretation of productivity growth, where $(1 - P)$ (or $(P - 1)$ *if* $P > 1$) is the proportional output change that cannot be explained by changes in inputs x and is thus attributed to technological change.

The interpretation of the production indexes T in 2.2 or P in 2.3 typically depends on the situation being considered. Such interpretations are discussed next.

Time series interpretation

Most industries exhibit technical progress over time. As a result, time series production data from any industry typically reflect some shift in technology across observations. As noted in equation 2.3b, the indexes T, P and P' become identical under the assumption that (x, y) are technically efficient. Then, $T = P$ becomes the Malmquist productivity index discussed by Caves *et al.* (1982, p. 1407). Indeed, assuming that (x, y) is always on the production frontier, $(1 - T)$ is a measure of the rate of technical change for inputs-outputs (x, y) compared to the reference technology F. In this context, if F represents some new technology, $T < 1$ means that the firm's old technology F' is not as good as the new technology F. Then, $(1 - T)$ measures the proportional reduction in inputs or cost (or, under CRTS, the proportional increase in outputs or revenue) associated with changing technology from F' to F. Caves *et al.* (1982) investigated the relationship between the productivity index T in equation 2.3 and the Christensen-Jorgenson (CJ) productivity index commonly estimated in the literature (Ball, 1985). Under optimizing behaviour, constant return to scale, and a translog cost specification, Caves *et al.* (1982, p. 1408) showed that the CJ index can be written as $[T(x^b, y^b, F_c^{\,a})/T(x^a, y^a, F_c^{\,b})]^{1/2}$. They also investigated the impact of the scale elasticity (reflecting departures from CRTS) on productivity measurement.

Cross section interpretation

Using cross section data, production analysis typically focuses on a set of economic units (firms or regions) at a given time within an industry. Assuming that the best available technology is available to all units within the industry, the concept of technical efficiency relates to the question of whether a firm uses the best available technology in its production process. This is precisely what is measured by the index T in 2.2, with F representing the best available technology. In this context, given an observed input-output vector (x, y), the Farrell index $T(x, y, F)$ in 2.2 provides a simple measure of technical efficiency, with $T \leq 1$. $T = 1$ implies that the firm is technically efficient and produces on the production frontier associated with technology F. Alternatively, $T < 1$ implies that the firm is not technically efficient as its inputs-outputs are below the production frontier

Panel data interpretation

It has just been argued that the indexes T and P can be interpreted as measuring productivity change from cross section data, as well as technical change in time series data. But is it possible to isolate technical efficiency effects from productivity effects? Without *a priori* information on the sources of inefficiency or technical change, the general answer to this question is no.

Indeed, knowing that a firm exhibits an index $T < 1$ does not distinguish between two alternative interpretations. On the one hand, the firm may be a late adopter of new technology F and, by still using an old technology, it appears below the production frontier of F. On the other hand, it is possible that the firm adopted the latest technology but is technically inefficient in its use. Thus, it is in general difficult to distinguish between the slow adoption of new technology and technical inefficiencies unrelated to technical progress. These difficulties have led many researchers to circumvent the problem by ignoring production inefficiency issues in productivity analysis (e.g. Binswanger, 1974; Ball, 1985), as well as ignoring technical change issues in efficiency analysis (e.g. Chavas and Aliber, 1993).

Yet, it seems reasonable to expect that, in most industries, a slow adoption of new technology can coexist with unrelated production inefficiencies. A way of dealing with this issue is to use panel data, which can allow for a simultaneous investigation of production efficiency and technical change. The cross-section part of the data can then be used to estimate time-specific production frontiers. And the time series part of the data can be used to evaluate the rate of productivity growth as the frontier technology shifts over time. Thus, the cross-section information can generate production efficiency indexes, while the time series information can yield indexes of technical change. Fare *et al.* (1994) give an example of this approach, which distinguishes empirically between productivity growth and efficiency change. However, this approach requires two conditions to be satisfied. First, at each time period, every unit in the cross-section sample must face a comparable production technology. Second, at each time period, there must be enough cross-section units observed on the production frontier (in order to provide a reliable empirical estimate of the production technology). Whether these conditions are satisfied or not would need to be assessed in the evaluation of the approach.

2.3 Non-parametric productivity analysis

Given a set of production data, how can the indexes T or P just discussed be empirically estimated? This can be done using either parametric methods or non-parametric methods. This paper focuses on the use of non-parametric methods in production analysis. This section briefly reviews some key results on non-parametric production methods obtained by Afriat (1972), Hanoch and Rothschild (1972), Diewert and Parkan (1983), Varian (1984) and Banker and Maindiratta (1988).

Again, consider a competitive firm choosing the input-output vector $(x, y) \geq 0$ under technology F. Assume that it behaves in a way consistent with the profit maximization hypothesis. Let $p = (p_1, ..., p_m)' > 0$ denote the $(m \times 1)$ vector of output prices, and $r = (r_1, ..., r_n)' > 0$ be the $(n \times 1)$ vector of input prices. Then, the firm production decisions are made as follows:

$$\max_{y,x} \{p'y - r'x: (-x, y) \in F\}, \qquad (2.5)$$

The solution to 2.5 gives the profit maximizing output supplies and input demand correspondences denoted by $y^*(p, r)$ and $x^*(p, r)$.

Consider that the firm is observed making production decisions τ times. Let S be the set of these observations: $S = \{1, 2, ..., \tau\}$. The t-th observation on production decisions is denoted by (y_t, x_t), with corresponding prices (p_t, r_t), $t \in S$. Economic rationality for production decisions is defined in terms of profit maximizing behaviour as stated in equation 2.5. It can be said that a production set F rationalizes the data $\{(y_t, x_t; p_t, x_t): t \in S\}$ if $y_t \in y^*(p_t, r_t)$ and $x_t \in x^*(p_t, r_t)$, $t \in S$. A key linkage between observable behaviour and production theory is given next.

Proposition 1: (Afriat, 1972; Varian, 1984)

The following conditions are equivalent:

a) *There exists a production set that rationalizes the data* $\{(y_t, x_t; p_t, r_t): t \in S\}$ *according to 2.5.*
b) *The data satisfy the Weak Axiom of Profit Maximization (WAPM):*

$$p_t' y_t - r_t' x_t \geq p_t' y_s - r_t' x_s,\ t \in S,\ s \in S. \qquad (2.6)$$

Given 2.6, there exists a family of convex, negative monotonic production sets F that rationalizes the data in T according to 2.5, and satisfies $F^i \subset F \subset F^o$, *where*

$$F^i = \{(y, -x): \Sigma_{t \in S} y_t \lambda_t \geq y;\ \Sigma_{t \in S} x_t \lambda_t \leq x;\ \Sigma_{t \in S} \lambda_t = 1;\ \lambda_t \geq 0,\ t \in S;\ x \geq 0,\ y \geq 0\}, \qquad (2.7a)$$

and

$$F^o = \{(y, -x): p_t' y - r_t' x \leq p_t' y_t - r_t' x_t,\ t \in S;\ x \geq 0;\ y \geq 0\}. \qquad (2.8)$$

Equation 2.6 states that the *t*-th profit $(p_t' y_t - r_t' x_t)$ is at least as large as the profit that could have been obtained using any other observed production decision $(p_t' y_s - r_t' x_s),\ s \in S$. It gives necessary and sufficient conditions for the data $\{(y_t, x_t; p_t, r_t): t \in S\}$ to be consistent with profit maximization 2.5. This is useful as a means of testing the relevance of production theory in particular situations. Perhaps more importantly, proposition 1 provides a basis for recovering some representations of the underlying production technology. More specifically, it identifies a whole family of production sets that are consistent with the data and the profit maximization hypothesis. This family is bounded by F^i in 2.7a and F^o in 2.8. Proposition 1 states that F^i in 2.7a gives the inner bound while F^o in 2.8 is the outer bound representation of the underlying technology (Afriat, 1972; Varian, 1984). These representations are of considerable interest since they are empirically tractable and provide all the information necessary to conduct production analysis. The inner-bound representation F^i in 2.7a has been commonly used in applied efficiency analysis, where it has been called data envelopment analysis or DEA. Note that it requires only data on input-output quantities. In contrast, the outer-bound representation F^o in 2.8 requires data on both prices and quantities for inputs-outputs.

The Afriat-Varian non-parametric results reported in proposition 1 assume that all data points in *S* are consistent with the profit maximization hypothesis. However, this assumption is not always empirically satisfied. Thus, there is a need to extend the Afriat-Varian non-parametric analysis to allow for situations where profit maximizing behaviour does not hold for all observations in *S*. Such an extension was proposed by Banker and Maindiratta (1988). In the situation where equation 2.6 is not satisfied for all $s, t \in S$, Banker and Maindiratta proposed a method relying on the subset of data points that are consistent with profit maximization. This subset is given by:

$$E = \{t: \Delta_t = 0;\ \Delta_t = \max_s [(p_t' y_s - r_t' x_s) - (p_t' y_t - r_t' x_t): s \in S];\ t \in S\}. \qquad (2.9)$$

Clearly, the criterion function Δ_t in 2.9 always satisfies $\Delta_t \geq 0$ for all $t \in S$. And $\Delta_t = 0$ only if there does not exist any data point $s \in S$ such that $p_t' y_t - r_t' x_t < p_t' y_s - r_t' x_s$, i.e. such that equation 2.6 is violated. As a result, any observation in $E \subset S$ is necessarily consistent with profit maximization with respect to all data points in *S*. For this reason, Banker and Maindiratta call *E* the efficient subset of *S*. Banker and Maindiratta obtained the following results.

Proposition 2: (Banker and Maindiratta, 1988)

Assuming that E is non-empty, the following conditions are equivalent:

a) *There exists a production set that rationalizes the data* $\{(y_t, x_t; p_t, r_t): t \in E\}$ *according to 2.5, and satisfies* $(-x_t, y_t) \in F$ *for all* $t \in S$.

b) *The data satisfy the Weak Axiom of Profit Maximization (WAPM):*

$$p_t' y_t - r_t' x_t \geq p_t' y_s - r_t' x_s, \; t \in E, \; s \in S. \quad (2.10)$$

Given 2.10, there exists a family of convex, negative monotonic production sets F that rationalizes the data in E according to 2.5, and satisfies $(-x_t, y_t) \in F$ *for all* $t \in S$, $F^i \subset F \subset F_E^o$, *where* F^i *is given in 2.7a and*

$$F_E^o = \{(-x, y): p_t' y - r_t' x \leq p_t' y_t - r_t' x_t, \; t \in E; \; x \geq 0; \; y \geq 0\}. \quad 2.11$$

Note that proposition 2 reduces to proposition 1 when $E = S$. However, it allows for inconsistencies between the data in S and profit maximization whenever E is a proper subset of S. Note that such inconsistencies may arise because of technological progress across observations. In this case, proposition 2 would be particularly relevant in productivity analysis. Since the observations in E are consistent with profit maximization, their efficiency cannot be refuted by the data. In contrast, the observations that are in S but not in E are inconsistent with profit maximization. Moreover, F^i in 2.7a and F_E^o in 2.11 can be used as inner bounds and outer bounds representations of the underlying technology F. In turn, such representations can be used to evaluate production efficiency and technical change. Note that the inner-bound representation F^i is the same data envelopment analysis (DEA) representation 2.7a found in proposition 1. Again, it requires only data on input-output quantities. However, the outer-bound representation F_E^o in 2.11 differs from the one found in proposition 1, F^o in 2.8. Again, evaluating F_E^o requires data on both prices and quantities for inputs-outputs.

This approach proposed by Banker and Maindiratta (1988) has one drawback. There are situations where the efficient subset E can be much smaller than the set S. This occurs when the number of observations in E (used to evaluate the outer-bound representation F_E^o) is significantly smaller than the number of observations in S (used to evaluate the inner-bound counterpart). This could be undesirable. For example, if E were to consist of only a few data points, the associated technology F_E^o would have few kinks, implying a relatively flat production frontier. Although not inconsistent with production theory, such a representation of the real world may be somewhat unrealistic. This has motivated Chavas and Cox (1997) to propose a modification of the Banker and Maindiratta approach that does not suffer from this drawback.

While the above analysis was presented under a general variable-return-to-scale (VRTS) technology F, it may be of interest also to consider the case of the constant-return-to scale (CRTS) technology F_c given in 2.4. Then, the results stated in propositions 1 and 2 can be appropriately modified. First, under CRTS, the inner-bound representation of technology given in 2.7a becomes

$$F_c^i = \{(-x, y): \textstyle\sum_{t \in S} y_t \lambda_t \geq y; \; \sum_{t \in S} x_t \lambda_t \leq x; \; \lambda_t \geq 0, \; t \in S; \; x \geq 0, \; y \geq 0\}, \quad (2.7b)$$

which satisfies $F^i \subseteq F_c^i$. The set F_c^i in 2.7b is a convex, negative monotonic production set that rationalizes the data and satisfies $(-x_t, y_t) \in F_c^i$ for all $i \in S$. It also satisfies the definition of CRTS: $(-\gamma x, \gamma y) \in F_c^i$ for all $\gamma > 0$, indicating that a proportional rescaling of all inputs and outputs always remains feasible. The difference between 2.7a and 2.7b is slight: 2.7a restricts the weights λ_t to sum to one, while 2.7b does not (see Fare, Grosskopf and Lovell, 1985). Not requiring the weights λ_t to sum to one implies that the proportional rescaling of all inputs-outputs in 2.7a is unrestricted (with the proportionality factor being $\gamma = \sum_{t \in S} \lambda_t$). This feasible rescaling of all inputs and outputs is precisely what characterizes a CRTS technology.

Second, the outer-bound representation given in 2.8 or 2.11 can also be appropriately modified under CRTS. It is well known that profit maximization and CRTS implies zero profit: $p_t'y_t - r_t'x_t = 0$. Then, following Afriat (1972), Varian (1984), and Banker and Maindiratta (1988), the outer-bound representations given in 2.8 and 2.11 would be obtained under CRTS, with the efficiency set E defined under the additional condition that $p_t'y_t - r_t'x_t = 0$. Alternatively, the analysis could be conducted under cost minimization and CRTS, as suggested by Varian. Again, the proposed modification discussed by Chavas and Cox (1997) could apply in this context as well.

The above discussion indicates practical ways of evaluating technology from production data, using non-parametric methods. Once the appropriate production technology is evaluated, it provides a basis for estimating the technical efficiency and productivity indexes T and P discussed in section 2.2. In fact, these two steps can be conveniently combined into a single step. Indeed, equations 2.7a, 2.7b, 2.8 or 2.11 are linear. Substituting these representations into 2.1, 2.2 or 2.3 generates simple linear programming problems (Fare, Grosskopf and Lovell, 1985). Since solving linear programming problems is not difficult, this means that the empirical implementation of the proposed methodology is fairly simple, as illustrated in the next section.

2.4 Empirical analysis

In this section, the usefulness of this approach applied to international agricultural productivity is illustrated. The analysis uses FAO annual data for inputs and outputs of 12 countries for the period 1960-1994. The 12 countries are: Brazil (BRA), Burkina Faso (BFA), China (CHN), France (FRA), India (IND), Madagascar (MDG), Mexico (MEX), Peru (PER), Poland (POL), Thailand (THA), Tunisia (TUN), and USA (USA). Outputs consist of two categories: crops and livestock. Inputs consist of four categories: fertilizer, labour, land and farm machinery. Fertilizer is measured by the total fertilizer weight. Labour is measured by rural population. Land is the area in cultivated land. And the number of tractors is used as a proxy variable for farm machinery. Note that these measured do not correct for possible effects of input quality changes on productivity.

Using FAO data, a non-parametric analysis of agricultural productivity both over time and across countries is presented. Since the FAO data only report quantity information, this investigation is focused on the inner-bound representation of technology given by 2.7a and 2.7b. This has two implications. First, it means that the analysis does not require any assumption about production behaviour. For example, it does not demand that inputs-outputs be chosen so as to maximize profit. This can be an advantage to the extent that production decisions may have more complex motivations than just profit maximization. For example, in an uncertain world, risk minimization may also be relevant. Second, by neglecting price information, little priori information is imposed on marginal rates of substitution. While diminishing marginal productivity is imposed (since the feasible sets F^i or F_c^i are convex), the marginal physical product of any input in principle can vary between zero and infinite. Allowing for such a wide range of possibilities gives additional flexibility to the analysis. This enhanced flexibility should also reflect more accurately the information content of the data used in the analysis.

The empirical analysis proceeds in two steps. In a first step, a time series analysis of productivity for each country over the period 1960-1994 is conducted. This should provide useful information about agricultural technological change in each country over the last few decades. Note that this approach estimates a separate production frontier for each country. As a result, it does not require that the production technology is similar across country. On the one hand, this can be a significant advantage to the extent that agro-climatic conditions as well as physical and human capital can vary significantly across countries. While such factors can in principle be incorporated in the analysis, measuring them accurately is typically difficult. On the other hand, by associating each country with a different technology, this approach does not yield information on cross-country differences in technology and productivity.

In a second step, a cross-section analysis of productivity across countries is presented. To allow for the possibility that technology may change over time, the cross-section analysis is conducted for selected periods. This should provide useful information on cross-country productivity at a given time period as well as its evolution over time. However, as discussed in section 2.2, this requires two conditions to be met: 1) all countries should face a similar technology during any given period; and 2) obtaining a reliable estimate of the production technology each period demands that enough observations be located on the production frontier.

Starting start with the first step: a time series analysis is conducted for each country. Let (x_t, y_t) denote the t-th observation on inputs-outputs, $t \in S$, where S is the set of time series data for a given country. Using the VRTS representation of the technology F^i given in 2.7a, how can the technical efficiency index $T(x, y, F^i)$ in 2.2 be evaluated? This can be obtained as follows

$$T(x, y, F^i) = 1/D(x, y, F^i)$$

$$= \text{Min}_\delta \{\delta: (-\delta \cdot x, y) \in F^i\}$$

$$= \text{Min}_{\delta,\lambda} \{\delta: \textstyle\sum_{t\in S} y_t \lambda_t \geq y;\ \sum_{t\in S} x_t \lambda_t \leq \delta \cdot x;\ \sum_{t\in S} \lambda_t = 1;\ \lambda_t \geq 0,\ t \in S\}, \qquad (2.12a)$$

for some $x \geq 0, y \geq 0$. In general, $T(x, y, F^i)$ satisfies $0 < T(x_t, y_t, F^i) \leq 1$ for all $t \in S$. Expression 2.12a is a standard linear programming problem. As discussed in sections 2.2 and 2.3, it provides a convenient basis to evaluate productivity.

Alternatively, using the CRTS representation of the technology F_c^i given in 2.7b, how can the technical efficiency index $T(x, y, F_c^i)$ in 2.2 be evaluated? This can be obtained as follows

$$T(x, y, F_c^i) = 1/D(x, y, F_c^i)$$

$$= \text{Min}_\delta \{\delta: (-\delta \cdot x, y) \in F_c^i\}$$

$$= \text{Min}_{\delta,\lambda} \{\delta: \textstyle\sum_{t\in S} y_t \lambda_t \geq y;\ \sum_{t\in S} x_t \lambda_t \leq \delta \cdot x;\ \lambda_t \geq 0,\ t \in S\}, \qquad (2.12b)$$

for some $x \geq 0, y \geq 0$. Since $F^i \subseteq F_c^i$, it is clear that $T(x, y, F_c^i) \leq T(x, y, F^i)$. In general, $T(x, y, F_c^i)$ satisfies $0 < T(x_t, y_t, F^i) \leq 1$ for all $t \in S$. Again, expression 2.12b is a standard linear programming problem that provides a convenient basis to evaluate productivity.

Equation 2.12b was used to estimate the technical efficiency index $T(x_t, y_t, F_c^i)$ for each of the 12 countries, using time series data from t equals 1960 to 1994. In this context, for each country, F_c^i is a representation of the best CRTS technology that was available between 1960 and 1994. As discussed in section 2.2, these indexes provide a basis to evaluate productivity growth in each country. The results are presented in Table 2.1.

Table 2.1 shows that the technical efficiency indexes T vary from a low of 0.690 for Burkina Faso in 1977 to its upper-bound of one. In general, the T index tends to decrease during the 1960s, reach a minimum some time in the early or late 1970s, and rise to its upper-bound of one in the early 1990s. The decrease in technical efficiency found in most countries during the late 1960s appears somewhat puzzling. This could possibly be due to environmental degradation. But this is not consistent with the results obtained for Madagascar. While Madagascar has suffered significant soil erosion, deforestation and ecological deterioration over the last few decades, it exhibits one of the least amounts of technical inefficiency. Indeed, its lowest T index is 0.915 in 1979, which follows closely India (T equals 0.935 in 1979) and Thailand (T is

Table 2.1 Technical efficiency indexes T: time series analysis conducted for each country

year	BRA	BFA	CHN	FRA	IND	MDG	MEX	PER	POL	THA	TUN	USA
1961	1.000	0.963	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1962	1.000	0.927	0.969	1.000	0.988	1.000	1.000	1.000	1.000	1.000	0.965	0.956
1963	0.951	0.914	1.000	0.949	0.988	0.985	0.962	0.966	0.972	1.000	1.000	0.941
1964	1.000	1.000	1.000	0.911	0.986	0.995	1.000	1.000	1.000	1.000	1.000	0.969
1965	1.000	1.000	1.000	0.959	0.965	0.922	1.000	0.950	0.988	1.000	1.000	0.900
1966	1.000	1.000	1.000	0.916	0.963	1.000	1.000	1.000	1.000	1.000	1.000	0.865
1967	0.954	0.979	1.000	0.908	0.961	1.000	0.984	0.990	1.000	0.958	1.000	0.858
1968	0.989	1.000	1.000	0.904	0.994	1.000	0.987	0.919	1.000	0.981	0.892	0.855
1969	1.000	0.999	0.953	0.870	0.993	0.991	0.910	0.950	0.990	1.000	0.828	0.842
1970	0.991	0.985	1.000	0.852	1.000	0.991	0.965	1.000	0.962	1.000	0.785	0.853
1971	0.975	1.000	1.000	0.860	0.986	0.948	0.990	1.000	0.932	0.949	0.935	0.869
1972	0.982	0.879	0.918	0.862	0.929	0.980	0.972	0.876	0.972	0.920	0.844	0.864
1973	0.965	0.706	0.968	0.911	0.976	0.972	0.988	0.898	1.000	1.000	0.924	0.815
1974	0.978	0.740	1.000	0.953	0.946	1.000	0.985	0.889	1.000	0.971	0.886	0.848
1975	0.890	0.801	0.965	0.953	0.983	1.000	0.930	0.899	0.987	1.000	0.964	0.833
1976	0.905	0.696	0.977	0.943	0.992	0.968	0.940	0.858	1.000	1.000	0.974	0.878
1977	0.900	0.690	0.872	0.919	1.000	0.940	1.000	0.843	0.970	0.940	1.000	0.868
1978	0.798	0.750	0.896	0.929	1.000	0.989	1.000	0.806	1.000	1.000	0.909	0.847
1979	0.803	0.797	0.840	0.970	0.935	0.906	0.947	0.830	1.000	0.919	0.763	0.875
1980	0.848	0.751	0.766	0.989	0.947	0.915	1.000	0.780	0.972	1.000	0.853	0.850
1981	0.872	0.759	0.814	1.000	0.986	0.944	0.971	0.854	0.897	0.990	0.868	0.899
1982	0.860	0.776	0.865	1.000	0.979	0.914	0.887	0.924	0.869	0.947	0.841	0.915
1983	0.919	0.827	0.872	0.994	1.000	0.919	0.907	0.916	0.893	0.984	0.901	0.876
1984	0.877	0.832	0.903	1.000	1.000	0.963	0.935	0.963	0.944	0.987	0.871	0.870
1985	0.979	0.945	0.964	0.981	1.000	0.940	0.994	0.983	0.944	1.000	0.978	0.900
1986	0.883	1.000	0.972	0.982	1.000	0.955	0.915	0.886	1.000	0.919	0.982	0.934
1987	0.967	0.955	0.876	0.992	1.000	0.968	0.937	0.937	0.961	0.921	1.000	0.922
1988	0.967	0.993	0.824	0.983	1.000	0.964	0.907	1.000	0.975	0.987	0.945	0.943
1989	1.000	0.948	0.831	0.963	1.000	1.000	0.896	1.000	0.989	1.000	0.966	0.917
1990	0.981	0.962	0.884	0.972	1.000	0.990	0.984	0.942	1.000	0.985	1.000	0.929
1991	1.000	1.000	0.880	1.000	0.988	0.996	0.963	1.000	1.000	1.000	1.000	0.941
1992	1.000	1.000	0.907	1.000	1.000	1.000	0.931	1.000	0.937	1.000	0.975	0.975
1993	1.000	1.000	1.000	0.997	1.000	1.000	0.977	1.000	1.000	0.974	1.000	0.957
1994	1.000	1.000	1.000	1.000	1.000	0.997	1.000	1.000	0.807	1.000	1.000	1.000

0.919 in 1979 and 1986). Thus, the decrease in productivity in the late 1960s seems hard to explain.

Also surprisingly, for each country, the technical efficiency index *T* in Table 2.1 starts with a value of one some time in the early 1960s and ends up with a value of one in the early 1990s. This suggests that, in general, the technology of the early 1990s is similar to the one in the early 1960s. In other words, the results in Table 2.1 suggests that, overall, there was little technological progress in agriculture over the last few decades. This seems counterintuitive: *a priori*, one would expect to find some significant technical progress over the last few decades (e.g. due to the green revolution). It is known that parts of the yield increases during the green revolution were associated with a significant rise in fertilizer and pesticides use. Caution should be exercised not to attribute such effects to technological change: they may simply correspond to a move along a given production frontier as more inputs are being used. However, significant and steady genetic progress has taken place in agriculture, for both crops and livestock. It is expected that at least part of this genetic progress would contribute directly to agricultural productivity growth in most countries. The results in Table 2.1 appear to be at odds with this conjecture. They are also at odds with previous estimates of productivity growth found in the literature. For example, there is strong evidence that agricultural productivity growth in the United States has been steady and large over the last few decades (Capalbo and Antle, 1988; Ball, 1985;

Table 2.2 Technical efficiency indexes T: cross-section analysis conducted for selected three-year periods

year	BRA	BFA	CHN	FRA	IND	MDG	MEX	PER	POL	THA	TUN	USA
1962	1.000	0.949	1.000	1.000	1.000	1.000	0.919	1.000	1.000	1.000	0.810	0.990
1963	0.975	0.957	1.000	1.000	0.961	0.990	0.823	0.943	1.000	1.000	1.000	1.000
1964	1.000	1.000	1.000	1.000	0.926	1.000	0.867	0.988	1.000	1.000	0.933	1.000
1965	1.000	1.000	1.000	1.000	0.957	0.973	0.834	1.000	1.000	1.000	0.930	1.000
1966	1.000	1.000	1.000	0.986	0.844	1.000	0.864	1.000	1.000	1.000	0.673	1.000
1967	0.966	1.000	1.000	1.000	0.721	1.000	0.863	1.000	1.000	1.000	0.732	1.000
1968	1.000	1.000	1.000	1.000	0.684	1.000	0.894	1.000	1.000	0.984	0.779	0.999
1969	1.000	1.000	0.980	0.990	0.681	0.996	0.904	1.000	1.000	1.000	0.553	1.000
1970	0.993	1.000	1.000	1.000	0.723	1.000	0.891	1.000	0.993	1.000	0.758	1.000
1971	1.000	1.000	1.000	1.000	0.681	0.985	0.932	1.000	1.000	1.000	1.000	1.000
1972	1.000	0.966	0.986	1.000	0.626	1.000	1.000	0.969	1.000	0.932	0.903	1.000
1973	1.000	0.895	1.000	1.000	0.671	1.000	1.000	0.969	1.000	1.000	0.978	1.000
1974	1.000	0.955	1.000	1.000	0.720	1.000	1.000	1.000	1.000	0.974	0.893	0.952
1975	1.000	1.000	1.000	1.000	0.688	1.000	1.000	1.000	0.978	0.999	1.000	1.000
1976	1.000	0.935	1.000	1.000	0.700	0.981	1.000	1.000	1.000	1.000	0.892	1.000
1977	1.000	0.952	1.000	1.000	0.694	0.907	1.000	1.000	1.000	1.000	1.000	1.000
1978	0.976	1.000	1.000	0.985	0.684	1.000	1.000	0.971	1.000	1.000	0.893	0.992
1979	0.991	1.000	1.000	1.000	0.650	1.000	0.978	1.000	0.982	0.928	0.888	1.000
1980	0.978	0.989	0.931	0.993	0.645	1.000	1.000	0.899	1.000	1.000	1.000	0.980
1981	1.000	1.000	0.949	1.000	0.680	1.000	1.000	0.974	0.895	1.000	0.792	1.000
1982	1.000	1.000	1.000	1.000	0.657	0.997	1.000	1.000	0.848	0.971	0.688	1.000
1983	1.000	1.000	0.942	1.000	0.657	1.000	1.000	1.000	0.806	1.000	0.947	0.984
1984	0.956	0.910	1.000	1.000	0.653	1.000	0.987	0.985	0.838	0.987	0.770	0.979
1985	1.000	1.000	1.000	0.992	0.658	1.000	1.000	1.000	0.827	1.000	0.906	1.000
1986	0.908	1.000	1.000	1.000	0.710	1.000	1.000	1.000	0.858	1.000	0.831	1.000
1987	0.999	0.924	1.000	1.000	0.693	1.000	1.000	0.939	0.895	0.957	0.972	0.992
1988	1.000	0.921	1.000	1.000	0.680	1.000	1.000	1.000	0.840	1.000	0.722	1.000
1989	1.000	1.000	0.972	0.996	0.761	1.000	0.923	1.000	0.839	1.000	0.619	0.980
1990	0.987	0.969	1.000	1.000	0.728	1.000	1.000	0.967	1.000	0.872	0.875	1.000
1991	1.000	0.954	1.000	1.000	0.735	1.000	1.000	1.000	1.000	0.946	1.000	1.000
1992	1.000	1.000	0.906	1.000	0.798	1.000	0.927	1.000	1.000	0.990	0.904	0.965
1993	1.000	0.978	1.000	0.996	0.801	1.000	0.974	1.000	1.000	0.879	1.000	0.957
1994	1.000	0.914	1.000	1.000	0.786	0.981	1.000	1.000	0.854	0.877	0.822	1.000

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Jorgenson and Gollop, 1992; Chavas and Cox, 1997; Chavas *et al.*, 1997; Ball *et al.*, 1997). Similar evidence has also accumulated in agriculture around the world (Evenson and Kislev, 1975; Pardey *et al.*, 1991; Rosegrant and Evenson, 1992; Craig *et al.*, 1997). Such discrepancies with the results reported in Table 2.1 appear puzzling. This issue is further discussed below.

Now, consider the second step: a cross-section analysis conducted for all 12 countries during specific periods. Changing the notation, let (x_t, y_t) denote the t-th observation on inputs-outputs for the 12 countries during a given period, $t \in S$, where S is the corresponding data set. Then, the technical efficiency index $T(x_t, y_t, F^i)$ is given by equation 2.12a above under the variable-return-to-scale (VRTS) technology F^I, and the technical efficiency index $T(x, y, F_c^i)$ is given by equation 2.12b under constant-return-to-scale (CRTS) technology. Since $F^i \subseteq F_c^i$, it is clear that $T(x, y, F_c^i) \leq T(x, y, F^i)$. Thus, in general, $0 < T(x_t, y_t, F_c^i) \leq T(x_t, y_t, F^i) \leq 1$ for all $t \in S$. Again, expression 2.12a or 2.12b is a standard linear programming problem that provides a convenient basis to evaluate productivity.

Equation 2.12b was used to estimate the technical efficiency index $T(x_t, y_t, F_c^i)$ for all 12 countries for selected periods covering three consecutive years. The choice of three consecutive years was made on the grounds that technology might change, but slowly, over time. Thus the analysis is conducted separately for 11 different periods: 1962-64, 1965-67, …, up to 1992-94. In this context, F_c^i is a representation of the best technology available across all 12 countries during each period. As such, it can be interpreted as characterizing the "international agricultural production function" during that period. As discussed in section 2.2, the estimated technical efficiency indexes can provide a basis to evaluate cross-country productivity and its evolution over time. The results are presented in Table 2.2 for the 11 periods, starting in 1962-64, and ending with 1992-94.

Table 2.2 shows that technical efficiency index *T* varies from a low of 0.626 for India in 1972 to its upper-bound of one. In general, the *T* index for India tends to be lower than any other state. Except for 1962, it is always less than one, and it stays in the range 0.6 to 0.7 for most of the 1970s and 1980s. No other country exhibits such a pattern. This seems difficult to explain. Table 2.2 shows that most countries are often found to be on the "international production frontier". For example, China and France exhibit a technical efficiency index equal to one in 26 of the 33 cases evaluated, or 78 percent of the time. For all countries except India and Tunisia, the technical efficiency index is equal to one at least 18 times out of 33, i.e. at least 54 percent of the time. Thus, there appears to be a sufficient number of observations located on the international production frontier to obtain a meaningful representation of the international production technology. The part that appears surprising in Table 2.2 is the fact that, except for India, the technical efficiency indexes are often close to one. As discussed in section 2.2, this suggests that agricultural technology is fairly uniform both across countries and over time. This is rather surprising since this analysis did not take into consideration cross-country variations in agro-climatic conditions, in infrastructure and in human capital. At a minimum, one would expect to find that agricultural productivity depends significantly on soil quality and climate. Thus, except for India, the lack of strong evidence of productivity differences across countries appears puzzling.

The above results indicate that the agricultural sector may have been subject to little technical change and productivity growth both over time and across countries. This would suggest that most output changes (i.e. crop and livestock output) are due to changes in inputs (i.e. fertilizer, farm equipment, land and labour). As noted above, this surprising finding is at odds with the empirical literature on agricultural productivity. Is it possible to explain this discrepancy? Possible explanations can be linked to the methodology used as well as the data.

The results presented in Tables 2.1 and 2.2 are obtained from equation 2.12b, which relies on a CRTS representation of the technology F_c^i. What if equation 2.12a was used instead, relying on a VRTS representation of the technology? It has been seen above that $T(x, y, F_c^i) \leq T(x, y, F^i)$. Thus, the technical efficiency indexes $T(x, y, F_c^i)$ reported in Tables 2.1 and 2.2 are in fact a lower bound to the ones one would obtain under VRTS. Given that the indexes *T* have an upper bound of one, using 2.12a under VRTS would generate higher technical efficiency index than the ones reported in Tables 2.1 and 2.2, and thus less evidence of productivity growth. It follows that, under VRTS, the evidence in favour of technical change and productivity growth would become even weaker!

Could it be that the results reflect a misspecification of the production technology? For example, this analysis does not control for agro-climatic conditions, for infrastructure, and for human capital. Incorporating such variables in the analysis would influence the results. This would amount to increasing the number of inputs in the production technology. How would that affect the analysis and findings? Increasing the number of inputs in equation 2.12a or 2.12b amounts to increasing the number of constraints without changing the number of variables optimized. Since 2.12a or 2.12b are minimization problem, this would imply in general an increase in the value of the optimized objective function. In other words, this would tend to increase the value of the technical efficiency index *T* toward one. Thus, introducing additional inputs in the analysis would further weaken the evidence in favour of technical change and productivity growth. Intuitively, these additional inputs would give new ways of explaining output changes, thus providing less evidence of technical change. This suggests that model misspecification is not a good candidate for explaining some of the surprising results.

Two possible explanations remain: 1) the inner bound representation of the production technology may make it difficult to uncover evidence of productivity growth; and 2) data problems.

First consider the implications of using the inner bound representation F^i of the technology. In principle, this specification is flexible in the sense that it does not impose restrictions on the possibility of substitution among inputs. It is also flexible in the sense that it imposes the basic concept of diminishing marginal productivity without requiring a parametric specification. Finally, as stated in propositions 1 and 2, it is consistent with the sample data. As such, it provides a simple representation of technology that is close to the data and the theory, with a minimum of ad hoc assumptions. Also, as illustrated by Fare *et al.* (1994), it can in principle generate evidence of significant productivity growth. All these characteristics appear quite positive, thus suggesting the general usefulness of the approach. If so, why is there not more evidence of agricultural technical change? As argued by Chavas and Cox (1997), it may be that the inner-bound and outer-bound representations discussed in propositions 1 and 2 do not provide tight estimates of the underlying technology. Then, there would be a fairly wide range of technologies that are consistent with the data and production theory. In this context, empirical searches (e.g. through the parametric testing of alternative functional forms) for a "true technology" may be futile. The non-parametric bounds identified in propositions 1 and 2 can help better assess the range of identification (or underidentification) of the underlying technology, and better evaluate the strength of the information that a particular data set can yield. While both inner-bound and outer-bound representations of technology are consistent with the data, it may be that the outer-bound representation is more realistic than the inner bound. The reason is that the inner-bound measure given in 2.7a allows the marginal physical product of inputs to vary between zero and infinity. While this is theoretically possible, it seems rather unlikely that real-world observations would cover such a wide range. In contrast, the outer-bound measures given in 2.8 or 2.11 constrain the marginal physical product to equal price ratios. This follows from the fact that, under profit maximization, the profit hyperplane must be tangent to the production frontier. As long as observed prices do not take extreme values, it would exclude the possibility of uncovering either "very small" or "very large" marginal physical products. In some sense, these exclusions may appear realistic. Thus, the use of price information in the outer-bound representations may in fact help obtain a more reasonable estimate of the production technology. This suggests a need to complement the cross-country productivity analysis presented here with an analysis based on outer-bound representations of the technology. This would require obtaining comparable price information on inputs and outputs both over time and across space. This seems to be a good topic for further research.

Second, consider the issue of data quality. As in any analysis, good data are required to obtain good results. In the context of this paper, this relates to measuring both input-output quantities as well as quality. As much as possible, input-output quantities should be obtained using superlative quantity indexes, i.e. quantity indexes that are exact indexes associated with a flexible function form. An example of a superlative index is the Theil-Tornqvist index commonly used in productivity analysis (Ball, 1985; Jorgenson and Gollop, 1992). This is a superlative index since it is an exact index associated with a translog production function. Note that, in this sample, fertilizer is measured at the total quantity of fertilizer used. This is not a superlative quantity index. This suggests that there are avenues to improve the measurement of quantity information used in this report. Also, whenever possible, quality changes should be taken into consideration. This may be relevant for most netputs. For example, given the spatial heterogeneity of land quality, it would be useful to correct land input for quality changes. This may be particularly relevant if the quantity changes involve marginal, less productive land. A similar argument would apply to fertilizer, labour or machinery. Thus, there are also avenues for improving netput measurement through quality adjustments. Implementing such changes across countries may be a significant challenge. However, it would help generate better data and thus improve the reliability of the empirical analysis. This is particularly crucial to the extent that quality concerns about current data may undermine the reliability of our results.

2.5 Conclusions

This paper proposes a non-parametric method to investigate the time-series and cross-section evolution of agricultural productivity. It relies on estimating technical efficiency and productivity indexes based on a non-parametric representation of the technology. The method is flexible in that it imposes little *a priori* restrictions on technology beyond diminishing marginal productivity. It is also easy to implement empirically: the technical efficiency and productivity indexes can be obtained as solutions of simple linear programming problems. This is illustrated in an empirical application to FAO data for 12 countries over the period 1960-1994. The analysis focuses on agricultural technology characterized by two outputs (crops and livestock) and four inputs (land, labour, machinery and fertilizer). It uses the inner-bound representation of the underlying technology in the estimation of technical efficiency indexes. The non-parametric approach discussed in this paper can help economists better assess the nature of the underlying technology, allowing a greater awareness of the strengths as well as limitations of the data, and a better evaluation of their informational content.

The empirical results indicate only weak evidence of agricultural technical change and productivity growth both over time and across countries. This would suggest that most of changes in agricultural outputs can be explained by corresponding changes in inputs. For example, crop output can rise due to an increase in fertilizer use, without requiring a shift in the production technology. But this is a rather surprising finding. Indeed, there is much evidence of strong productivity growth in agriculture over the last few decades. This reflects in part the large genetic progress that has taken place for both crops and livestock. Also previous literature has found much empirical evidence supporting agricultural technological progress. Such discrepancies with the empirical results are puzzling.

In an attempt to explain such differences, two elements are apparent. The first is the need to complement the analysis with an outer-bound representation of technology. Such a representation would require obtaining comparable price information on inputs-outputs both over time and across countries. Making use of price information would restrict *a priori* the possible range for the marginal physical products of inputs. As argued by Chavas and Cox (1997), such restrictions may give a better representation of technology and help uncover stronger evidence of technical change and productivity growth. Second, the findings may reflect data problems. Poor measurements of input-output quantities seem to contribute to the discrepancies between these results and previous literature on agricultural productivity analysis. If so, there is a need to refine and improve the measurement of inputs and outputs across countries. Addressing these issues presents significant challenges for future work.

References

Antle, J.M. 1983. Infrastructure and aggregate agricultural productivity: international evidence. *Economic Development and Cultural Change,* 31: 609-619.

Afriat, S.N. 1972. Efficiency estimation of production functions. *International Economic Review,* 13(October): 568-598.

Arrow, K.J., Chenery, B.H., Minhas, B.S. & Solow, R.M. 1961. Capital-labor substitution and economic efficiency. *Review of Economic and Statistics,* 43: 225-250.

Ball, V.E. 1985. Output, input and productivity measurement in US Agriculture, 1948-1979. *American Journal of Agricultural Economics,* 67: 475-486.

Ball, V.E., Bureau, J.C., Nehring, R. & Somwaru, A. 1997. Agricultural productivity revisited. *American Journal of Agricultural Economics,* 79(November): 1045-1063.

Banker, R.D. & Maindiratta, A. 1988. Nonparametric analysis of technical and allocative efficiencies in production. *Econometrica,* 56(November): 1315-1332.

Bauer, P.W. 1990. Recent developments in the econometric estimation of frontiers. *Journal of Econometrics,* 46: 39-56.

Bhattaccharjee, J.P. 1995. Resource use and productivity in world agriculture. *Journal of Farm Economics,* 37: 57-71.

Binswanger, H.P. 1974. The measurement of technical change biases with many factors of production. *American Economic Review,* 64: 964-976.

Capalbo, S.M. & Antle, J.M. 1988. *Agricultural productivity: measurement and explanation* Washington, D.C.: Resources for the Future, Inc.

Caves, D.W., Christensen, L.R. & Diewert, W.E. 1982. The economic theory of index numbers and the measurement of input, output, and productivity. *Econometrica,* 50: 1393-1414.

Chavas, J.P. & Aliber, M. 1993. An analysis of economic efficiency in agriculture: a nonparametric approach. *Journal of Agricultural and Resource Economics,* 18:1-16.

Chavas, J.P. & Cox, T.L. 1997. Production analysis: a non-parametric time-series application to US agriculture. *Journal of Agricultural Economics,* 48: 330-348.

Chavas, J.P., Aliber, M. & Cox, T.L. 1997. An analysis of the source and nature of technical, change: the case of US agriculture. *Review of Economics and Statistics*: 482-492.

Christensen, L. & Jorgenson, D. 1970. US real product and factor input, 1929-1967. *Review of Income and Wealth,* 16: 19-50.

Craig, B., Philip, J., Pardey, G. & Roseboom, J. 1997 International productivity patterns: accounting for input quality, infrastructure and research. *American Journal of Agricultural Economics,* 79: 1064-1076.

Debreu, G. 1951. The coefficient of resource utilization. *Econometrica,* 19: 273-292.

Diewert, W.E. & Parkan, C. 1983. Linear programming tests of regularity conditions for production functions. *In* W. Eichhorn, R. Henn, K. Neumann, and R.W. Shephard, eds. *Quantitative studies on production and prices.* Wurzburb: Physica Verlag.

Evenson, R.E. & Kislev, Y. 1975. *Agricultural research and productivity.* New Haven: Yale University Press.

FAO. 1986. *International comparisons of agricultural produtcion aggregates.* FAO, Economic and Social Development, Paper #61, Rome.

Fare, R., Grosskopf, S. & Lovell, C.A.K. 1985. *The measurement of efficiency of production.* Boston: Kluwer-Nijhoff Publishers.

Fare, R., Grosskopf, S., Norris, M. & Zhang, Z. 1994. Productivity growth, technical progress and efficiency change in industrialized countries. *American Economic Review,* 84: 66-83.

Farrell, M.J. 1957. The measurement of productive efficiency. *Journal of the Royal Statistical Society*, Series A, 120: 253-290.

Farrell, M.J. & Fieldhouse, M. 1962. Estimating efficient production under increasing returns to scale. *Journal of the Royal Statistical Society*, Series A, 125: 252-267.

Forsund, F.R., Lovell, C.A.K. & Schmidt, P. 1980. A survey of frontier production functions and their relationship to efficiency measurement. *Journal of Econometrics,* 13: 5-25.

Hanoch, G. & Rothschild, M. 1972. Testing the assumptions of production theory: a non-parametric approach. *Journal of Political Economy,* 80: 256-275.

Hayami, Y. 1969. Sources of agricultural productivity gap among selected countries. *American Journal of Agricultural Economics,* 51: 564-575.

Hayami, Y. 1970. On the use of the Cobb-Douglas production function on the cross-section analysis of agricultural production. *American Journal of Agricultural Economics,* 52: 327-329.

Hayami, Y. & Ruttan, V.W. 1970. Agricultural productivity differences among countries. *American Economic Review,* 60: 895-911.

Hayami, Y. & Ruttan, V.W. 1985. *Agricultural development: an international perspective.* Baltimore: The Johns Hopkins University Press.

Jorgenson, D.W. & Gollop, F.M. 1992. Productivity growth in US agriculture: a postwar perspective. *American Journal of Agricultural Economics,* 74: 745-750.

Kawagoe, T. & Hayami, Y. 1983. The production structure of world agriculture: an intercountry cross-section analysis. *The Developing Economies,* 21: 189-206.

Kawagoe, T., Hayami, Y. & Ruttan, V.W. 1985. The inter-country agricultural production function and productivity differences among countries. *Journal of Development Economics,* 19: 113-132.

Mundlak, Y. Forthcoming. Production and supply. *In* B. Gardner and G. Rausser, eds. *Handbook of Agricultural Economics.* New York: North Holland.

Mundlak, Y. & Hellinghausen, R. 1982. The inter-country agricultural production frontier: another view. *American Journal of Agricultural Economics,* 64: 664-672.

Nguyen, D. 1979. On agricultural productivity differences among countries. *American Journal of Agricultural Economics,* 61: 565-70.

Pardey, P.G., Roseboom, J. & Anderson, J.R. 1991. *Agricultural research policy: international quantitative perspectives.* Cambridge: Cambridge University Press.

Rosegrant, M.W. & Evenson, R.E. 1992. Agricultural productivity and sources of growth in South Asia. *American Journal of Agricultural Economics,* 74: 757-761.

Seiford, L.M. & Thrall, R.M. 1990. Recent developments in DEA: the mathematical programming approach to frontier analysis. *Journal of Econometrics,* 46: 7-38.

Shephard, R.W. 1970. *Theory of cost and production functions.* Princeton: Princeton University Press.

Varian, H. 1984. The nonparametric approach to production analysis. *Econometrica,* 52(May): 579-597.

3. Agricultural productivity and natural resource depletion

Donna J. Lee and Lydia Zepeda

This paper presents a model for evaluating agricultural production that incorporates agriculturally induced resource externalities. A two step calibration procedure is presented to parameterize multi-crop, multi-input production models. First a programming model is presented which uses existing market information and observed economic activity to estimate unobserved (shadow) costs to the industry. Second, the estimated shadow costs are incorporated with the observed market costs and used within a programming framework to calibrate empirical non-linear multi-crop, multi-input production functions. Minimum data requirements of the modelling procedure are described. The calibration procedure is illustrated with a synthetic data set consisting of five crops and three inputs. A framework for evaluating the link between agricultural activities and natural resource depletion is laid out and natural resource depletion rates are computed for five common environmental and resource problems. A numeric illustration is used to estimate the welfare effects from a variety of agricultural policies.

3.1 Introduction

Increasing agricultural productivity has long been a part of national goals to combat hunger, meet subsistence needs, reduce dependence on imports for food and fibre, improve the balance of trade, increase national security and achieve sustainable growth. Griliches (1987) defined productivity as "…a ratio of some measure of output to some index of input use." Growth in agricultural output can be attained through expansion in farmed area, intensification of production and improvement in input use efficiency. However, full consideration of the effect of agriculture on the local environment is important since short-run gains to agricultural productivity can have long-run implications on national output levels. In many countries, agricultural expansion has accelerated depletion of natural resource stocks, deteriorated environmental quality and encroached on sensitive ecosystem habitats. Examining the full effects of agricultural expansion policies on national welfare necessitates productivity analysis of broader scope.

Understanding productivity

At the onset, researchers hypothesized that expansion of capital and labour could explain the bulk of productivity growth. Studies employing growth accounting methods were able to explain about ten to 15 percent of growth with physical capital formation (Cornwall, 1987; Denison, 1967 and 1987). Bosworth (1982) similarly found little evidence linking the decline in productivity in the 1970s to reduced capital formation during that decade. The residual, approximately 85 to 90 percent unexplained growth, has been broadly interpreted as efficiency gains, technological progress, improved economies of scale and a "measure of our ignorance" (Cornwall, 1987). A better explanation of the large residual may be the reliance on *partial analysis* in the 1950s, 1960s and 1970s where capital formation was narrowly defined and important input factors were left out of the analysis. Omission of relevant input factors can lead to biased and unreliable results.

Subsequent studies have attempted a more complete analysis through inclusion of physical inputs such as fertilizer and pesticides. Other researchers included labour inputs in their analyses, specifically human capital formation to explain growth (Antholt, 1994; Beal, 1978; Evenson and McKinsey, 1991; Jamison and Lau, 1982; Nehru and Dhareshwar, 1994; Pardey, Roseboom and Craig, 1992; Pray and Evenson, 1991; Rosegrant and Evenson, 1992). Griliches (1963) incorporated the *quality* of labour in his study on agricultural production in the United States. He used education as a measure of labour quality and included research and extension expenditures to explain growth in productivity. In this fashion, Griliches was able to explain virtually all "unexplained growth" with economies of scale, changes in labour quality and investment in research and development. Support for this work can be found in Abramovitz (1956), Kendrick (1973) and Solow (1957). These authors show that input *quality* (increased efficiency of input use) rather than *quantity* can account for three-quarters of the early post-war growth in the United States economy (Metcalfe, 1987). In recent work by Auraujo, Chambas and Foirry (1997), Lachaal (1994), Lin (1992), McMillan, Whalley and Zhu (1989) and Wiens (1983), public policy reforms were investigated to explain productivity growth.

External effects of productivity

Agricultural productivity *loss* resulting from environmental degradation has been well documented. Wolman (1985), for example, reports significant losses due to soil erosion of up to 40 percent in the former USSR, 25 percent in the United States, 30 percent in Haiti and 25 percent in Nigeria. In the growth model literature, however, the effects of environmental degradation are conspicuously absent. Part of the omission may be explained by lack of necessary data. Agronomic information on land quality, for example, is not routinely collected and reported with other information on land use. It is also interesting to note that natural habitats are often classified as "unimproved land" and assigned an economic value of *zero* (FAO, 1996). This is despite the fact that in their "unimproved" state, many lands provide a net positive flow of economic goods and services.

To address the gap in the literature, this paper develops a link between agricultural activity and natural resource stocks to demonstrate a method for including the welfare effects of resource stock depletion in agricultural productivity and policy analyses.

Measuring productivity

Methods for assessing contribution to productivity growth have included the following: index numbers or growth accounting techniques (Antle and Capalbo, 1988; Diewert, 1976), econometric techniques (Capalbo and Vo, 1988) and mathematical programming procedures (Chavas and Cox, 1992). The drawbacks of these methods are as follows. Growth accounting imposes strong assumptions about the technology, while econometric approaches are data intensive. Both accounting and econometric methods require that the data be aggregated. Mathematical programming methods, while relatively less restrictive, are not statistical and therefore preclude hypothesis testing and construction of confidence intervals.

The premise of this work is an empirical procedure for calibrating flexible agricultural production models which can be used to evaluate the effect of agricultural policy on agricultural productivity, agricultural sector activity, agricultural returns and natural resources.

3.2 Calibrated agricultural production models

Agricultural production functions are typically estimated with regression techniques. For some applications, however, the available data are too sparse to parameterize the functions needed to address the problems at hand. For example, an annual data series may report labour, land use and income, but not irrigation water use, capital investment and variable costs. The lack of a corresponding data series prohibits econometric estimation.

When available production data are too sparse for standard regression techniques, functions can be parameterized using calibration procedures. Traditional calibration approaches have relied on constraints to replicate base year observations. The problem is that *ad hoc* constraints can inadvertently restrict the range of plausible alternatives, thereby limiting the model's uses as a policy tool.

Recent use of calibration methods for economic modelling includes Zhuang (1996) who applied a calibration procedure to estimate a computable general equilibrium model (CGE) of the Chinese economy. He first calibrated the CGE to a base year then modified the model with econometrically estimated behavioural equations to capture the 1983 economy, a year not in competitive equilibrium. Deviations of the base from the equilibrium were attributed to the distorting influence of many years under a command economy.

Pavilos and Yip (1997) examined the case of a small open economy exposed to free trade. They modelled the economy with a dynamic generalized cash advance system and used calibration methods to determine the value of a tariff on imported consumer goods.

A good description of calibration methods can be found in Kydland and Prescott (1982). The reader is also referred to Gregory and Smith (1989) and Kim and Pagan (1993) for excellent reviews of the literature.

The agricultural sector produces a variety of crops and allocates scarce resource inputs to those crops. Except for some rigidity in input and output markets, it can be assumed that production decisions are made jointly and in response to market signals. Market signals are reflected in the prices of agricultural products and the costs of production inputs. Due to heterogeneity in quality of resource inputs, access to resources and access to output markets it is expected to observe a variety of crops produced. The dispersion of values is concealed when the data are highly aggregated, which is found to be the case when working with macro-level data. Models parameterized with aggregate data may not accurately reflect or explain observed cropping patterns and agricultural activities using a strict, profit maximizing, production framework.

A programming model parameterized with *observed* input use rates, cropping mix and output levels may suggest that at current prices and costs, agricultural profits will be maximized when *only* the most profitable crops are grown (in contrast to what is observed in practice). To reproduce observed activity, previous researchers have imposed the following restrictive assumptions: (1) farmers maximize profits subject to (calibration) constraints specified to replicate observed activity; or (2) farmers do not maximize profit, but optimize over another variable (e.g. output, revenue, etc.).

The method described in this paper postulates that because the available market information is aggregated and incomplete, reported price and cost data do not comprise a complete picture of the economic signals that the agricultural sector faces. The approach presented here retains profit maximization as the primary objective, assumes farm production is efficient and employs a set of less restrictive and theoretically more plausible constraints to parameterize production functions.

Step 1: deriving the resource shadow values

If agricultural resource inputs were being allocated efficiently, one would expect to observe the following efficiency criteria. The value marginal product of each crop equals the marginal cost of inputs at observed output levels. In reality, this widely accepted economic condition of profit maximization is rarely observed. An empirical explanation is that the marginal cost of resource use includes the observed market cost plus some additional costs, i.e. costs faced by producers that do not appear in economic data series. The first step of the calibration procedure is aimed at estimating these additional or "shadow" costs. To this end, linear programming methods are used to derive the shadow cost of resource use under the following five assumptions.

(1) Resource use in the agricultural sector is efficient.

(2) All producers have equal access to non-limiting production inputs (e.g. water, fertilizer and seed). In other words, input markets are perfectly competitive.

(3) Only one input is limiting (and therefore has a positive shadow cost).

(4) Producers have equal access to output markets, that is output markets are perfectly competitive.

(5) Pecuniary and pollution externalities between producing regions do not exist.[1]

The shadow cost is defined to be an additional cost to agricultural producers of using resource inputs not reported in economic data series. Through observation of agricultural sector activity (i.e. choice of resource inputs and selection of output levels) under observed market prices and input costs, the true marginal cost of inputs used in production can be determined and thereby the shadow cost can be imputed.

Following Lee and Howitt (1996), for each resource input $j = 1, ..., J$, the shadow cost 8 is defined to be the marginal profitability of the input in the lowest valued crop $i = 1, ..., I$.^{j} In equation 3.1, p_i is crop price, Q_i is total production of crop i, X_{ij} is input quantity, r_j is input cost and a_{ij} is the linear rate of input use.

$$\lambda_j = \min_{i=1...I} \left[\frac{\left(p_i \frac{\partial Q_i}{\partial X_i} - r_j \right)}{a_{ij}} \right] \tag{3.1}$$

Equation 3.1 can also be expressed as,

$$\lambda_j = \min \left[\frac{\left(p_1 \frac{\partial Q_1}{\partial X_1} - r_j \right)}{a_{1j}}, \frac{\left(p_2 \frac{\partial Q_2}{\partial X_2} - r_j \right)}{a_{2j}}, \ldots, \frac{\left(p_I \frac{\partial Q_I}{\partial X_I} - r_j \right)}{a_{Ij}} \right] \tag{3.2}$$

Following equation 3.2, the shadow cost for the j^{th} limiting resource input can be computed.

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1 These are strong assumptions that may not apply to all nations. If input and output markets are not perfectly competitive, or externalities exist between regions, a weaker assumption can be substituted without much loss. This may be done by assuming that a managing entity (e.g. the national government) regulates agricultural production and agricultural markets (through taxes, subsidies, quotas and mandates, for example), thereby fully internalizing the social cost of externalities and achieving efficiency within the agricultural sector. Externalities to other sectors may still exist.

Step 2: calibrating nonlinear production parameters

Using the shadow costs derived in Step 1 and observed market output prices, input costs, the non-linear production function parameters are calibrated. To assure that the calibrated production functions replicate an efficiently operating agricultural sector the following efficiency constraints are specified:

- The production function satisfies first-order necessary conditions for profit maximization.
- The production function satisfies second-order sufficiency conditions for profit maximization.
- The functions allow for multiple crops to be grown.
- In a normative setting, the production functions reproduce observed output levels and input use levels at observed market prices and market costs.

Model equations

Let crop output levels be represented by Q and be non-linear in input use X. For I crops and J inputs, Q is $(I \times 1)$ and X is $(I \times J)$. The production function parameters are given by α which is $(I \times (J+1))$.

$$Q = Q(\alpha, X) \tag{3.3a}$$

The observed output and input levels Q^0 and X^0 are given. The matrix of parameters α is to be calibrated. The first order condition for profit maximization is given by equation 3.4a implying that production efficiency exists when value marginal product equals marginal input cost. In equation 3.4a, p is an $(I\times1)$ vector of output prices and marginal input cost is given by r $(J\times1)$ plus the shadow cost λ $(J\times1)$.

$$p'\Delta_X Q = r + \lambda \tag{3.4a}$$

The second-order condition for profit maximization, concavity, can be fulfilled by equation 3.5a,

$$\Delta_X{}^2 Q < 0 \tag{3.5a}$$

Equation 3.6a assures that the calibrated production model $Q = Q(\hat{\alpha}'\ X)$ reproduces observed output levels Q^0 at the base level of resource allocation X^0.

$$Q^0 = Q(\hat{\alpha}'\ X^0) \tag{3.6a}$$

Equation 3.7a imposes constant returns to scale on the lowest valued crop in the region.

$$tQ^0 = Q(\hat{\alpha}'\ tX^0) \tag{3.7a}$$

Equation 3.8a equates the shadow value of the limiting input with the difference between average and marginal yield for each crop.

$$p'((X^0)_j^{-1}\ Q - \Delta_{Xj}\ Q) = \lambda_j \quad \text{for the limiting resource } X_j = X_L \tag{3.8a}$$

If noise exists in the data observations from faulty collection procedures, aggregation in the reported data, or another source, then the calibrated model is unlikely to fit the data exactly. To allow for noise in the data, equations 3.4a through 3.8a are appended with an error term ε to yield equations 3.4b through 3.8b. The production model parameters, α, are calibrated by minimizing the sum of the squared error terms as follows.

Choose α to minimize

$$E = \varepsilon'\varepsilon \text{ where } \varepsilon / [\varepsilon 1' \ \ \varepsilon 2' \ \ \varepsilon 3' \ \ \varepsilon 4']' \qquad (3.9)$$

Subject to:

$$p'\Delta_X Q = r + \lambda + \varepsilon 1 \qquad (3.4b)$$

$$\Delta^2_X Q < 0 \qquad (3.5b)$$

$$Q^0 = Q(\hat{\alpha}, X^0) + \varepsilon 2 \qquad (3.6b)$$

$$tQ^0 = Q(\hat{\alpha}, tX^0) + \varepsilon 3 \qquad (3.7b)$$

$$p'((X^0_j)^{-1} Q - \Delta_{Xj} Q) = \lambda_j + \varepsilon 4 \quad \text{for } X_j = X_L \text{ the limiting resource} \qquad (3.8b)$$

3.3 Data requirements

The methodology described here was developed for use with extremely parsimonious data (single observations). If the method is applied to larger data sets, the results will approximate those of restricted least squares. In general, however, when multiple observations of all model variables are available, the preferred method of estimation is least squares for attaining unbiased, efficient results, properties that are not guaranteed with calibration.

The calibration method described here can be used to evaluate aggregated national data. If disaggregated regional data are also accessible, calibration of regional production functions is recommended. The regional results can then be aggregated to assess the national effects of policy. In this way, analytic results will be more precise. Furthermore, regional results allow for interesting cross-regional comparisons and policy trade-offs.

The minimum data requirements are as follows: total annual crop production; average crop price; land use by crop; total land available for farming; average annual land cost by crop; annualized capital investment; cost of capital; rate of use for other inputs; and per unit cost of other inputs. Observations are needed for at least two crops.

Output data

Total annual production of each crop (or average yield per acre[2]) for the relevant crops grown in the country is needed in addition to the corresponding average wholesale or farm-gate price received for each crop.

Input data

Data on land, capital and other inputs are needed for this analysis. Land data requirements include: the total area of land farmed in each crop; the average annual per unit cost of land; and the total amount of land available for farming. If land is the limiting input, then the total available land for farming may be assumed equal to the sum of land in all crops.

Required data on capital include: the total annualized investment in capital for each crop; the cost of capital; and total capital available. If capital is a limiting input, then total available capital for farming may be assumed equal to the total capital investment in all crops.

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[2] 1 acre = 0.4 ha (approx.).

Other input data required may include the quantity and or quality of additional dominant inputs and their average per unit cost. Since a large number of different inputs are used in farming, it is critical that data are obtained on all inputs subject to change and they may vary by crop type. An analysis of irrigated crops, for example, should include water application rate and water cost. For dryland crops, labour use, pesticide use or fertilizer application rate may take precedent.

The calibration procedure can be applied using exclusively land and capital as inputs. However, the results will not be reliable if another important input is left out. Consider, for example, an evaluation of the effects of a policy restriction. If an important input is left out of the analysis, the model results may fail to anticipate input substitution as an adaptive response. The on-farm cost of policy will be overestimated and the net welfare effects of the policy may be underestimated.

3.4 Illustration of the two-step calibration procedure

The calibration procedure is illustrated here for a nation producing five crops A, B, C1, C2 and D using three basic production inputs: land, water and capital. Synthetic data for output levels and rates of input use are displayed in Table 3.1. Synthetic "observed" output prices and input costs are shown in Table 3.2.

Table 3.1 Observed output level and rate of input use per crop

Crop	Output level	Input use		
		Land	Water	Capital
I	Q_i	X_L	X_W	X_K
A	98.32	28.5	49.87	2.85
B	512.5	5	6.50	0.50
C1	1 084.00	8	8.80	0.80
C2	122.55	5.7	11.40	0.57
D	38.75	0.5	0.55	0.05

Table 3.2 Observed output price and input cost

Crop	Output price	Input cost (per unit)		
		Land	Water	Capital
I	p_i	r_L	r_W	r_K
A	50.62	0.055	0.008	0.10
B	1.95	0.04669	0.00891	0.10
C1	2.55	0.08635	0.01319	0.10
C2	17.21	0.091	0.01	0.10
D	3.22	0.06246	0.01123	0.10

Model specification

The production function is specified as Cobb-Douglas with inputs land (L), water (W) and capital (K):

$$Q_i = \alpha_{i0} X_{iL}^{\alpha_{iL}} X_{iW}^{\alpha_{iW}} X_{iK}^{\alpha_{iK}}, \qquad \text{for } i = \text{A, B, C1, C2 and D} \qquad (3.3b)$$

The parameterization problem is to find α that minimizes the sum of the squared errors (equation 3.9) subject to:

$$p_i \alpha_j Q_i/X_{ij} = r_j + \lambda_j + \varepsilon 1_j \quad \text{for } j = L, W, K \qquad (3.4c)$$

$$\alpha_j^2 Q_i/X_{ij}^2 < 0 \qquad (3.5c)$$

$$Q_i^0 = \alpha_{i0} \Pi X_{ij}^{0\ \alpha_{ij}} + \varepsilon 2 \qquad (3.6c)$$

$$\Sigma_j \alpha_{ij} = 1 + \varepsilon 3 \qquad (3.7c)$$

$$p_i (Q_i/X_{iL} - \alpha_j Q_i/X_{iL}) = \lambda_L + \varepsilon 4 \qquad (3.8c)$$

where X_L is the limiting resource and for all crops *i*.

Empirical results

Solving the system of equations given by equations 3.4c through 3.8c and 3.9 parameterized by the information in Tables 3.1 and 3.2 yields the calibrated Cobb-Douglas parameter values in Table 3.3. The calibrated model can be calibrated by comparing empirical output levels at observed input use rates to "observed" output levels. Input use rates from Table 3.1 and parameter values from Table 3.3 are used in equation 3.2b to arrive at estimated output Q^M. Validation results are shown in Table 3.4. Note that the predicted output levels Q^M are fairly close to observed output levels, Q^0 (from Table 3.1). For this synthetic data set, the model calibrated to within two percent.

Table 3.3 Calibrated production function parameter values

Crop	Calibrated parameters			
	Intercept	Land	Water	Capital
I	$\hat{\alpha}_0$	$\hat{\alpha}_L$	$\hat{\alpha}_W$	$\hat{\alpha}_K$
A	3.62	0.888	0.08	0.032
B	145.53	0.734	0.058	0.018
C1	327.00	0.539	0.042	0.015
C2	44.40	0.516	0.054	0.027
D	66.30	0.651	0.05	0.014

Table 3.4 Validation of calibrated model: comparison to observed output levels

Crop	Output		Calibration Error
	Observed	Calibrated Model Estimate	
I	Q^0	Q^M	
A	98.32	100.22	2 percent
B	512.50	522.06	2 percent
C1	1084.00	1095.28	1 percent
C2	122.55	122.43	<1 percent
D	38.75	39.29	1 percent

3.5 Interpretation and use of the empirical results

The calibrated results from section 3.4 provide sufficient information for estimating marginal product of capital, value marginal product of capital, marginal product of land and value marginal product of land. This section provides estimates of the value of marginal product for each crop. These values can be used to indicate which crops will yield the greatest net gains from capital enhancement policies and which crops will produce the highest net returns with area expansion policies.

Returns to capital investment

To compare returns to capital investment across crops, the marginal product of capital and the value of the marginal product of capital for each crop are computed. The marginal product of capital can give the increase in total crop output that will occur with a small infusion of capital. Multiplying the marginal product of capital by the price received for the crop, the value of the marginal product of capital is obtained, the value of additional output that would be generated by a small increase in capital investment.

The value of the marginal product of capital, VMP_K, is estimated using the calibrated slope coefficient on capital $\alpha_{i,K}$ (table 3.3); observed output of crop *i*, Q_i (Table 3.1); capital input level $X_{i,K}$ (Table 3.1); and the definition of the marginal product of capital, MP_K for a Cobb-Douglas production,

$$MP_{i,K} = \alpha_{i,K}\, Q_i / X_{i,K} \qquad (3.10)$$

The value of the marginal product of capital is defined by

$$VMP_K = p_i MP_K \qquad (3.11)$$

where p_i is the unit price of crop *i* (Table 3.2).

As shown in Table 3.5, the marginal product of capital for crop C1 is 20.32, the largest in the group. At the margin, a one unit increase in capital investment in crop C1 will result in a 20.32 unit increase in output of crop C1. By comparison, increasing the quantity of capital used in the production of crop A generates a 1.10 unit increase in output. In terms of units of output, crop C1 is the better investment. Comparing output units of different crops, however, is like comparing apples and oranges. To denominate crop outputs in comparable units, each crop's marginal product is multiplied by its own price and in this way the additional (marginal) revenue generated with a unit increase in capital investment can be evaluated.

Table 3.5 Marginal product of capital and value of the marginal product of capital at "observed" output levels and rate of input use

Crop *I*	Marginal Product of Capital $MP_{i,K}$	Value of the Marginal Product of Capital $VMP_{I,K}$
A	1.10	$55.88
B	18.45	$35.97
C1	20.32	$51.82
C2	5.80	$99.90
D	10.85	$34.93

Table 3.6 Marginal product of land and value of the marginal product of land at "observed" output levels and rate of input use

Crop *I*	Marginal Product of Land MP_L	Value of the Marginal Product of Land VMP_L
A	3.06	$155.07
B	4.57	$8.91
C1	5.17	$13.19
C2	0.58	$9.99
D	3.52	$11.34

Results indicate that a unit increase in capital investment in crop C2 will generate, at the margin, US$99.90 in revenues. It is important to note that the Cobb-Douglas specification assures that output is non-decreasing in input use. Furthermore, the output market is assumed to be perfectly competitive, that is, producers can sell as much as they produce without influencing the price. Therefore, within the model context value of the marginal product, VMP, is non-decreasing in all non-binding inputs and furthermore the "observed" level of capital is assumed to maximize production profits. In this illustration, capital is a non-binding resource, so any increase in capital above the observed level of use will lower net returns to agriculture.

In some countries, however, capital is the binding resource. Therefore, actions that increase the availability of capital to the agricultural sector through external investment, subsidization, guaranteed loans and technological innovations, would lead to an increase in net returns to agriculture.

Returns to agricultural area expansion

Results show that from an additional unit of land, crop C1 returns the greatest increase in total output as indicated by the computed marginal product of land for crop C1 of 5.1736. The crop with the smallest gain with an increase in land was C2 with a marginal product of land equal to 0.5805. The value of the marginal product of land or VMP_L, as shown in Table 3.6 is greatest for crop A. A unit increase in arable land will raise revenues by $155.08. By comparison, a unit increase in land planted in crop B will yield an increase of $8.92.

3.6 Natural resource depletion

Agricultural expansion encroaches on forested area, wetland habitats and desert communities. Once habitat is lost, tilling and irrigation of the land depletes soil nutrients and erodes topsoil. Supplemental nutrients can be introduced to enhance soil productivity, but excess nutrients can leach through the soil, contaminate underground aquifers and erode the quality of surface water systems.

For many years, the loss in natural resource amenities was accepted as a reasonable tradeoff to meet national needs for food, fibre and export products. Increased scarcity of natural resource stocks and greater awareness of the services provided by intact natural resources suggests that a more complete accounting of the welfare effects from resource stock depletion be considered in agricultural policy analysis. This section develops simple linking equations between agricultural activity and resource stock depletion, then uses those equations to evaluate the economic welfare effects of diminished stocks.

Evaluating natural resource depletion

National income accounting methods can be used to illustrate in a stylized manner the relationships among agricultural activities, natural resource stock depletion and social welfare. Borrowing notation from Dasgupta and Heal (1979) S measures the resource stock and $\dot{S}$ denotes the partial derivative of the stock with respect to time, that is, the change in the resource stock over time.

Depletion of the resource stock is indicated by: $\dot{S} < 0$

and regeneration or restoration of the resource stock will occur when: $\dot{S} > 0$.

In steady state, $\dot{S} = 0$.

The natural resource stock is assumed to provide a flow of services either in its intact state or through extraction. Non-timber goods and services from forested lands, for example, include food (nuts, roots, plants), materials (bark, plant fibres, etc.), CO_2 absorption, habitat and recreational services. If timber is harvested and not replanted, the forested area decreases and the flow of services diminishes as well. Thus, if the flow of services can be valued, then the loss in the flow of services due to the depletion of the resource stock can also be valued. Using a simple linear form, let v represent the present value of a unit of the resource stock. Then the present value of a change in the resource stock is expressed, $v\dot{S}$.

Social welfare from agriculture production, W, can be expressed as the utility from consumption of agricultural goods $U(C)$ less the value of the depletion of the resource stock:

$v\dot{S}$'

$$W = U(C) + v\dot{S} \tag{3.12}$$

In this simple case, assume that the society is closed so the amount available for consumption equals the quantity produced Q.

$$C = Q \tag{3.13}$$

The quantity of goods produced Q is a function of inputs into production given by equation 3.3a. Using the production functions developed in the previous section, α are the production function parameters and $\boldsymbol{X}$ is the matrix of inputs into production, in this case land, water and capital. If the rate of resource stock depletion corresponds with agricultural resource use, the change in the resource stock can be written as,

$$\dot{S} = h(\beta, \boldsymbol{X}) \tag{3.14}$$

Here β is the vector of stock depletion parameters. The following section describes simple functional forms for modelling natural resource stock depletion: groundwater stock depletion, groundwater contamination, deforestation, soil salinization and soil erosion. In the equations that follow, X_W represents water use, X_F measures fertilizer application, X_L indicates land in agriculture and X_K denotes investment in resource conserving capital.

Groundwater depletion

Most of the world's crops are irrigated with groundwater. When the rate at which water is pumped from the groundwater source exceeds the rate of recharge to the source, the stock of groundwater declines. The stock S can be defined as the volume of groundwater available for pumping. The change in the stock, $\dot{S}$, can be expressed as a function of the rate of water use X_W

$$\dot{S} = \beta_0 - \beta_1 X_W \tag{3.15}$$

Here β_0 is the natural recharge rate and β_1 relates the rate of irrigation water use with aquifer drawdown. For example, in an aquifer with a very slow recharge rate $\beta_0 \rightarrow 0$. In an aquifer with little or no return flow $\beta_1 \rightarrow 1$.

Groundwater quality contamination

Chemical and nutrient inputs to agricultural crops can leach through the soil and contaminate groundwater supplies. Following Kim, Sandretto and Lee (1999), groundwater contamination, from fertilizer application X_F and irrigation water X_W, can be expressed as follows where S is the stock of fertilizer in the groundwater:

$$\dot{S} = h(XF, XW, S) \tag{3.16}$$

Deforestation

Agricultural area expansion often occurs on cleared forestlands. Timber is harvested and then cleared for agriculture. Following Garcia (1998), where S is forested area, agricultural encroachment on forestland can be expressed as,

$$\dot{S} = -\dot{X}_L \tag{3.17}$$

Soil salinity

Irrigation water can leach salts from the soil into drainage water. If drainage water is returned to the water supply system, over time the water and the soils can become more and more saline (Lee and Howitt, 1996). If S measures water quality, then a simple function can be written indicating that water quality is decreasing (becoming more saline) in water application, X_W and increasing in improved irrigation technology, X_K.

$$\dot{S} = -\beta 2\, XW + \beta 3 XK \tag{3.18}$$

Soil erosion

Agricultural activities can erode top soil and deposit sediment in the waterways. After many years, the soil base can become depleted, crop yields decline and production becomes unprofitable. Typically, tillage and irrigation practices contribute to the rate of soil erosion. Where S is the stock of soil, soil erosion can be expressed as increasing in water use X_W and decreasing in investment in soil conserving capital X_K.

$$\dot{S} = -\beta 4\, XW + \beta 5 XK \tag{3.19}$$

3.7 Computing the welfare effects of agricultural resource stock depletion

The following example illustrates the welfare effects of depleting a resource stock, groundwater. Suppose irrigation water is being pumped from a slowly recharging aquifer. The rate of stock depletion is given by equation 3.15. Consider this simplest case. The recharge rate is very slow, $\beta_0 = 1.0$ and the discharge rate is equal to three-fourths the pumping rate, $\beta_1 = 0.75$.

Then, $\dot{S} = 1.0 \, X \, 0.75 \, XW.$

The social value of water in the aquifer is set equal to US$1.10 as shown in Table 3.8. Multiplying *v* by the annual change in stock, gives the value of stock depletion,

$v\dot{S}$ (Tables 3.8 and 3.9).

This illustration shows how to approximate the cost of an environmental externality arising from an agricultural activity. Results show that crop C2 yields the highest net welfare per acre (US$240.75) even when the externality is accounted for (Table 3.9). Crop A generates the largest external cost per acre (US$40.05). Production of crop D has a small beneficial impact on the environment, US$0.65 per acre, resulting from a water withdrawal rate that is lower than the recharge rate.

Table 3.7 Economic returns to agriculture

Crop	Revenue	Cost	Profit	Profit per Acre
	TR	*TC*	*B*	B/X_L
A	$4977.21	$2127.29	$2849.91	$99.99
B	$999.37	$309.16	$690.21	$138.04
C1	$2764.20	$847.74	$1916.45	$239.55
C2	$2109.08	$689.48	$1419.59	$249.05
D	$124.77	$39.10	$85.66	$171.33
	Total		$6961.82	

Table 3.8 Natural resource stock depletion (groundwater)

Crop	Stock unit value	Change in Stock	Value of Stock Depletion
	V	*S*	*vS*
A	$1.10	-36.4063	-$40.05
B	$1.10	-3.875	-$4.26
C1	$1.10	-5.6	-$6.16
C2	$1.10	-7.55	-$8.31
D	$1.10	0.5875	$0.65

Table 3.9 Natural resource stock depletion and net welfare

	Profit	Value of Stock Depletion	Net Welfare
Crop	B/X_L	*v S*	*W*
A	$100.00	-$40.05	$59.95
B	$138.04	-$4.26	$133.78
C1	$239.56	-$6.16	$233.40
C2	$249.05	-$8.31	$240.75
D	$171.33	$0.65	$171.98
Total	$897.98	-$58.13	$839.85

3.8 Conclusions

This paper presented an empirical approach for evaluating agricultural production and analysing the economics of agriculturally induced resource externalities. The two-step calibration procedure presented here can be used to parameterize multi-crop, multi-input production models that closely reproduce observed input and output levels under observed market conditions in a relatively unconstrained setting. The parameterized model follows first order and second order conditions for profit maximization at observed output levels. An illustration with five crops and a Cobb-Douglas model specification in land, water and capital was used to demonstrate the procedure.

Empirical results were used to compute the value of the marginal product of capital to show how investment in capital accumulation can increase agricultural sector returns. A comparison of the computed value of the marginal product of capital between crops indicated which crops yield the greatest return to investment. Model results were also used to compute the value of the marginal product of land to reveal the marginal returns to area expansion. Comparing the value of the marginal product of land between crops reveals the crops that would contribute the greatest returns to the agricultural sector from additional area.

Simple linking equations between agricultural activities and natural stocks were proffered for groundwater overdraft, groundwater contamination, deforestation, soil salinization and soil erosion. The linking equations were parameterized and then used to demonstrate how to account for the social welfare effects of resource degradation from agricultural enhancement policies.

A logical extension of this work is an application of the calibration procedure to country level agricultural data and specification and parameterization of one or more of the linking resource depletion equations. Another interesting area of follow-up work is a side-by-side comparison of estimation results from the calibration methodology and econometric methodology.

References

Abramovitz, M. 1956. Resource and output trends in the United States since 1870. *American Economic Review*, Papers and Proceedings, 46 (May): 5-23.

Antholt, C.H. 1994. Getting ready for the twenty-first century: technical change and institutional modernization in agriculture. World Bank Technical Paper #217, February. Washington. DC. World Bank.

Antle, J. & Capalbo, S. 1988. An introduction to recent developments in production theory and productivity measurement. *In* S. Capalbo & J. Antle, eds. *Agricultural productivity measurement and explanation.* Washington, DC, Resources for the Future.

Auraujo, B., Chambas, C.G. & Foirry, J.P. 1997. Consequences de l'ajustement des finances publiques sur l'agriculture marocaine et tunisienne, unpublished FAO study, March.

Beal, D.W. 1978. Agricultural education and training in developing countries. *FAO studies in Agricultural Economics and Statistics*, *1952-1977*. Rome, FAO.

Bosworth, B. 1982. Capital formation and economic policy. *Brookings Papers on Economic Activity,* 2: 273-317.

Capalbo, S. & Vo, T. 1988. A review of evidence on agricultural productivity and aggregate technology. *In* S. Capalbo & J. Antle, eds. *Agricultural productivity measurement and explanation.* Washington, DC, Resources for the Future.

Chavas, J.P. & Cox, T. 1992. A nonparametric analysis of the influence of research on agricultural productivity. *American Journal of Agricultural Economics,* 74: 583-591.

Cornwall, J. 1987. Total factor productivity. *In* J. Eatwell, M. Milgate & P. Newman, eds. *The new Palgrave dictionary of economics*, vol 4. New York, USA, Stockson Press.

Dasgupta, P.S. & Heal, G.M. 1979. *Economic theory and exhaustible resources.* Cambridge, UK, Cambridge University Press.

Denison, E. 1987. Growth accounting. In J. Eatwell, M. Milgate & P. Newman, eds. *The new Palgrave dictionary of economics,* vol 2. New York, USA, Stockson Press.

Denison, E. 1967. *Why growth rates differ: postwar experience in nine Western countries.* Washington, DC, Brookings.

Diewert, W.E. 1976. Exact and superlative index numbers. *Journal of Econometrics,* 4: 115-145.

Evenson, R.E. & McKinsey, Jr., J.W. 1991. Research, extension, infrastructure, and productivity change in Indian agriculture. In R.E. Evenson and C.E. Pray, eds. *Research and productivity in Asian agriculture*, p. 158-184. Ithaca, USA, Cornell University Press.

FAO. 1996. A system of economic accounts for food and agriculture. *FAO Statistical Development Series 8*. Rome, FAO.

Garcia, M.C. 1998. Public forest resource management in a developing country: a study of deforestation in the Philippines. *Ph.D. Dissertation,* Department of Agricultural and Resource Economics, University of Hawaii, Honolulu, USA.

Gregory, A. & Smith, G. 1989. Calibration as estimation. *Econometric Reviews,* 9:57-89.

Griliches, Z. 1963. The sources of measured productivity growth: United States agriculture 1940-1960. *Journal of Political Economics,* 71: 331-346.

Griliches, Z. 1987. Productivity: measurement problems. In J. Eatwell, M. Milgate & P. Newman, eds. *The new Palgrave dictionary of economics,* vol 3. New York, USA, Stockson Press.

Jamison, D. & Lau, L. 1982. *Farmer education and farm efficiency*. Washington, DC, World Bank.

Kendrick, J. 1973. *Postwar productivity trends in the United States, 1948-1969.* New York, USA, National Bureau of Economic Research.

Kim, C.S., Sandretto, C. & Lee, D.J. 1999. Controlling groundwater quality with endogenous regulatory instruments. *Natural Resource Modeling*, 12 (2):249-272.

Kim, K. & Pagan, A. 1993. The econometric analysis of calibrated macroeconomic models. In H. Pesaran & M. Wickens, eds. *Handbook of Applied Econometrics*, Vol. 1. London, Blackwell Press.

Kydland, F. & Prescott, E. 1982. Time to build and aggregate fluctuations. *Econometrics,* 50:1345-70.

Lachaal, L. 1994. Subsidies, endogenous technical efficiency and the measurement of production growth. *Journal of Agriculture and Applied Economics,* 26 (July): 299-310.

Lee, D.J. & Howitt, R.E. 1996. Modeling regional agricultural production and salinity control alternatives for water quality policy analysis. *American Journal of Agricultural Economics,* 78: 41-53.

Lin, J.Y. 1992. Rural reforms and agricultural growth in China. *The American Economic Review,* 82 (March):34-51.

McMillan, J., Whalley, J. & Zhu, L. 1989. The impact of China's economic reforms on agricultural productivity growth. *Journal of Political Economy,* 97 (August):781-807.

Metcalfe, S. 1987. Technical change. In J. Eatwell, M. Milgate & P. Newman, eds. *The new Palgrave dictionary of economics,* vol 4. New York, USA, Stockson Press.

Nehru, V. & Dhareshwar, A. 1994. New estimates of total factor productivity growth for developing and industrial countries. World Bank Policy Research Working Paper #1313, June.

Pardey, P.G., Roseboom, J. & Craig, B.J. 1992. A yardstick for international comparisons: an application to national agricultural research expenditures. *Economic Development and Cultural Change,* 40: 333-349.

Pavilos, T. & Yip, C.K. 1997. The gains from trade for a monetary economy once again. *Canadian Journal of Economics,* 1: 208-223.

Pray, C.E. & Evenson, R.E. 1991. Research effectiveness and the support base for national and international agricultural research and extension programs. *In* R.E. Evenson and C.E. Pray, eds. *Research and Productivity in Asian Agriculture*. Ithaca, USA Cornell University Press.

Rosegrant, M.W. & Evenson, R.E. 1992. Agricultural productivity and sources of growth in South Asia. *American Journal of Agricultural Economics,* 74 (August): 757-761.

Solow, R. 1957. Technical change and the aggregate production function. *Review of Economics and Statistics,* 39 (August): 312-320.

Wiens, T.B. 1983. Price adjustment, the responsibility system, and agricultural productivity. *American Economic Review,* 73 (May):319-324.

Wolman, M.G. 1985. Soil erosion and crop productivity: a worldwide perspective. *In* R.F. Follett & B.A. Stewart, eds. *Soil erosion and crop productivity.* Madison, Wisconsin,USA, American Society of Agronomy.

Zhuang, J. 1996. Estimating distortions in the Chinese economy: a general equilibrium approach. *Economica, 3 (252):543-69.*

Section II
Regional trends in agricultural productivity and investment

4. Agricultural productivity for sustainable food security in sub-Saharan Africa

Keith D. Wiebe, Meredith J. Soule and David E. Schimmelpfennig[1]

This study examines trends in agricultural productivity in sub-Saharan Africa, identifying sources of growth as well as bottlenecks to growth. Existing research has consistently found that about three-quarters of the variation in agricultural productivity in sub-Saharan Africa can be explained by use of conventional inputs. For sub-Saharan Africa to meet its food security needs in the next ten years, will require one to two percent greater agricultural production per year than even the most optimistic projections. Policy reforms to improve physical infrastructure, political stability and the institutional environment are needed to facilitate access to and incentives to use conventional inputs as well as increase the application and returns to research.

4.1 Introduction

Agriculture is the principal source of food, livelihood and foreign exchange earnings in sub-Saharan Africa (SSA) (Badiane and Delgado, 1995). Production is a particularly important component of food security in SSA; commercial imports will contribute less than 10 percent of food supply over the next ten years (Rosen, 1997). As a result, agricultural productivity is critical to SSA's ability to meet food security and economic development objectives in the face of rapid population growth. SSA is projected to have the world's highest population growth rate over the next decade, at 2.5 percent per year, with nearly three-quarters of its workforce employed in agriculture (World Bank, 1998).

Yet evidence of agricultural performance in SSA is mixed at best. *Total factor productivity* in agriculture is estimated to have grown by an average of 1.3 percent annually between 1961 and 1991 for Africa as a whole (Lusigi and Thirtle, 1997). *Land productivity* in SSA agriculture rose by an average of 1.9 percent per year between 1980 and the mid-1990s, while increasing by 3.4 percent and 2.0 percent annually in South Asia and Latin America and the Caribbean, respectively (World Bank, 1998). Over the same period crop production in SSA grew by 2.7 percent per year, and food production grew by 2.4 percent per year. By contrast, *labour productivity* fell by an average of one percent per year in SSA agriculture. It increased by 1.9 percent and 2.5 percent per year, respectively, in South Asia and Latin America and the Caribbean. Complicating the differences in these indicators of agricultural productivity at the regional level are differences in the level and rate of change in each indicator across subregions and countries within SSA.

Trends in agricultural productivity in sub-Saharan Africa

Table 4.1 presents three measures of agricultural productivity and their rates of change, by region and country, based on data from the World Bank (1998) and Lusigi and Thirtle (1997). It is important to note that the value of agricultural output used in generating these statistics is

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Table 4.1 Agricultural productivity levels and trends

	Land productivity		Labour productivity		Labour/Land	Total factor productivity	
	Level ($/ha, 1993)	Growth rate (%/year, 1980-1993)	Level ($/worker, 1995)	rowth rate (%/year, 980-1995)	Ratio (workers/ha, 1991)	Level (index, 1991)	Growth rate (%/year, 1961-1991)
Sub-Saharan Africa	**68**	**1.9**	**392**	**-1.0**	**0.30**[a]	**0.8**[a]	**1.3**[a]
Central Africa							
Cameroon	313	1.7	827	-0.3	0.17	0.9	1.8
Central African Rep.	119	1.7	516	0.8	0.18	0.6	2.7
Congo	28	2.2	629	1.0	0.04	0.9	1.2
Gabon	74	0.8	1 516	0.5	0.05	0.3	-2.3
Zaire	113	2.4	219	0.0	0.34	0.6	8.1
East Africa							
Burundi	270	1.9	177	-1.4	1.01	2.9	3.4
Ethiopia	116	na	181	na	0.22	0.2	-1.7
Kenya	90	2.2	240	-0.7	0.13	0.6	1.9
Madagascar	34	2.1	178	-0.4	0.09	0.7	-0.1
Rwanda	378	-1.2	206	-2.6	1.42	0.7	6.1
Uganda	515	na	592	na	0.65	2.9	7.8
Sahel							
Burkina Faso	93	2.9	182	1.1	0.25	0.1	0.8
Chad	10	4.0	198	2.0	0.16	0.6	0.2
Gambia	199	1.6	167	-1.7	1.00	0.4	-1.5
Mali	33	2.5	259	0.2	0.06	0.8	0.8
Mauritania	7	2.6	na	na	0.01	0.1	-0.3
Niger	63	0.8	256	-0.9	0.20	0.7	1.5
Senegal	118	1.9	375	0.9	0.34	0.6	1.5
Somalia	na	na	na	na	0.05	0.8	1.2
Sudan	na	na	na	na	0.04	0.8	0.1
West Africa							
Benin	321	4.2	563	2.8	0.57	1.1	1.2
Côte d'Ivoire	212	0.6	1 354	-0.8	0.13	1.1	0.9
Ghana	227	0.4	684	-1.1	0.29	0.7	-0.5
Guinea	54	na	225	na	0.24	0.5	1.2
Guinea-Bissau	78	2.9	292	3.1	0.21	0.1	-2.1
Liberia		na	na	na	0.08	1.1	0.0
Nigeria	150	2.3	684	2.4	0.28	0.6	-0.3
Sierra Leone	123	0.4	344	-0.4	0.30	0.5	0.5
Togo	189	3.6	461	0.9	0.32	0.4	-1.3
Southern Africa							
Angola	9	na	149	na	0.07	0.4	-0.8
Botswana	5	1.7	483	1.4	0.01	0.2	1.3
Lesotho	24	-2.9	194	-2.7	0.23	0.1	-1.7
Malawi	153	0.4	156	-0.3	0.69	0.7	0.3
Mozambique	12	na	92	na	0.11	0.3	0.3
Namibia	9	0.9	1 458	0.8	0.004	1.4	1.0
South Africa	49	0.7	2 870	1.3	0.02	1.4	1.3
Swaziland	na	na	na	na	0.12	1.2	3.3
Tanzania	na	na	na	na	0.20	0.4	0.2
Zambia	7	1.2	100	-1.0	0.04	0.5	1.5
Zimbabwe	41	1.5	266	-0.7	0.27	0.7	2.0

Sources: Lusigi and Thirtle (1997), World Bank (1998). [a]Averages for all Africa. "na" no data available.

itself difficult to estimate because a large share of agricultural output is either consumed within the household that produces it, or is exchanged for commodities other than money (World Bank, 1998). The value of output is often estimated indirectly using a combination of methods, including reliance on estimates of yields and area under cultivation. To the extent that such attempts underestimate the true magnitude of agricultural output, estimates of agricultural productivity will themselves be biased downwards.

Output per unit of land, or crop yield, is commonly used by agricultural scientists to assess the success of new production practices. Land productivity is also used by national policy-makers to assess agricultural production for meeting national food security needs. Output per agricultural worker, on the other hand, may be a more important indicator of rural standards of living and welfare (Block, 1995). Recognizing that food may be acquired through exchange as well as production, income becomes an important determinant of access to food and thus of food security. As a result, labour productivity may be particularly important as an indication of the ability of agricultural workers to acquire sufficient food, whether or not they produce food themselves.

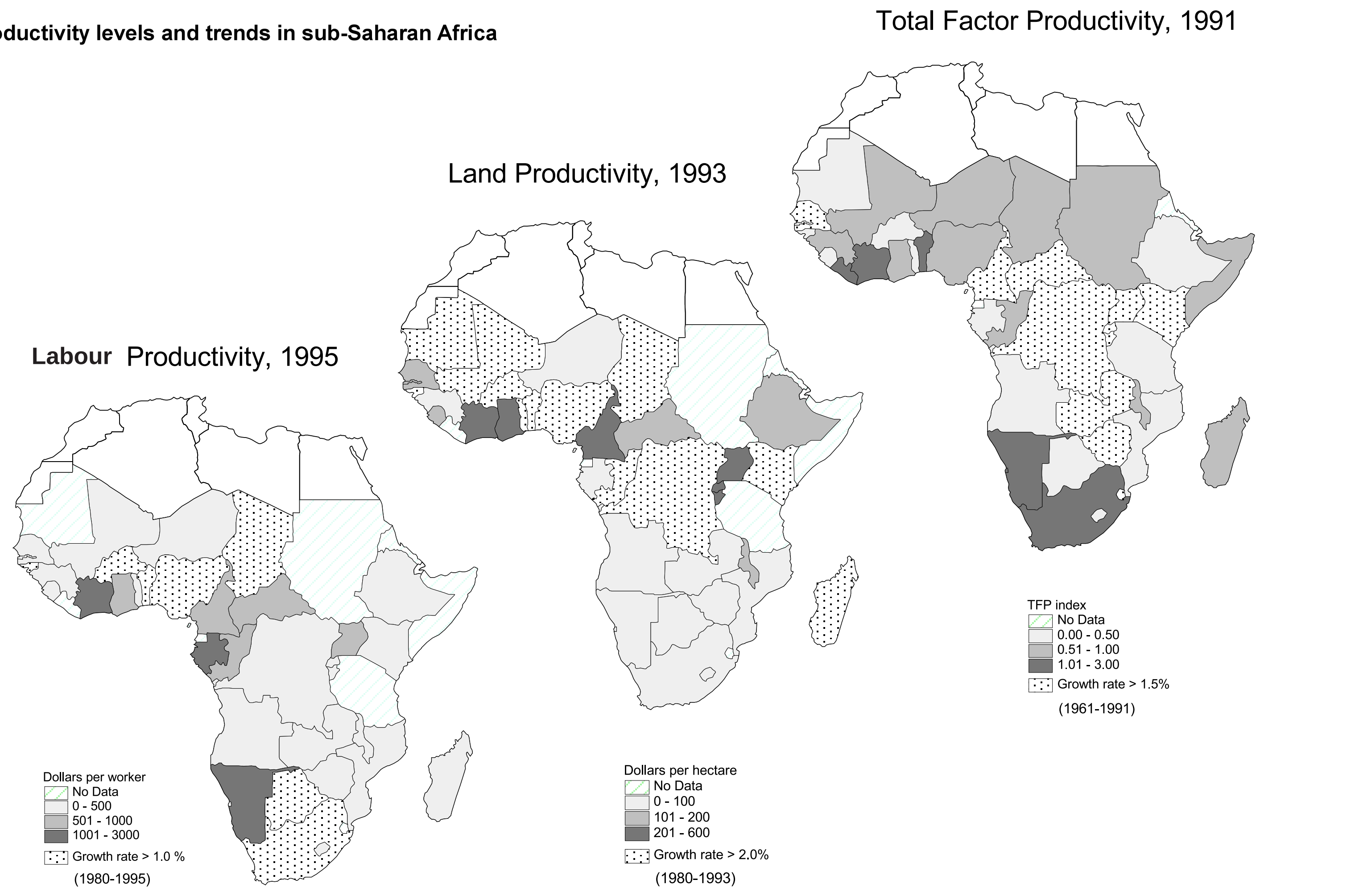
Land productivity averaged US$68 per hectare of agricultural land (measured as the sum of arable land, permanent cropland and permanent pasture) for SSA as a whole in 1993, compared with $519 in South Asia and $116 in Latin America and the Caribbean. Values ranged from $5-10 per hectare in the drier countries of Southern Africa and the Sahel to $200 per hectare and more in the East African highland countries and tropical West Africa. For SSA as a whole, land productivity grew at an average rate of 1.9 percent per year between 1980 and 1993, with slow to moderate growth in most countries. Land productivity grew most rapidly in the Sahelian countries and West Africa, and more slowly in Eastern and Southern Africa (Table 4.1). These patterns in land productivity levels and growth are also depicted in the second map in Figure 4.1.

Labour productivity averaged $392 per agricultural worker for SSA as a whole in 1995, this compares with $383 in South Asia and $2 292 in Latin America and the Caribbean. Values ranged from $100-$200 per worker in many countries in Eastern and Southern Africa and the Sahel to more than $500 per worker in parts of West and Central Africa. Labour productivity declined at an average rate of 1.0 percent per year for SSA as a whole between 1980 and 1995, with modest growth in West Africa and declines in Eastern and Southern Africa (Table 4.1). The first map in Figure 4.1 illustrates patterns of labour productivity. In contrast to the pattern evident for land productivity, the most rapid growth in labour productivity appears to be taking place in those countries that already have the highest levels of labour productivity. Perhaps this reflects the pull of off-farm employment opportunities, suggesting that disparities in labour productivity across countries may increase over time.

Low (or declining) labour productivity is consistent with high (or growing) land productivity in the context of a large (or expanding) agricultural labour force. Such patterns are evident in the agricultural labour/land ratios reported by Lusigi and Thirtle (1997) and presented in Table 4.1. The labour/land ratio is generally high in East Africa and low in Central and Southern Africa and the Sahel.

Land and labour productivity measures are both incomplete indicators of agricultural productivity, since they measure the productivity of only a single factor of production, and may well move in opposite directions. In an effort to address this problem, economists estimate total factor productivity (TFP), which measures changes in agricultural output relative to changes in an aggregated index of multiple inputs. TFP growth reflects factors such as technical change or improvements in infrastructure or research. It can also reflect failure to include or measure inputs such as depletion of soil or other natural resources.

FIGURE 4.1
Agricultural productivity levels and trends in sub-Saharan Africa



The the last two columns of Table 4.1 and third map in Figure 4.1 report estimates by Lusigi and Thirtle (1997) of TFP levels for 1991 and rates of change for 1961-91.[2] For Africa as a whole the TFP index estimated by Lusigi and Thirtle averaged 0.8. This indicates that on average, the productivity of the set of inputs measured was 0.8 times as high in 1991 as it was in the most efficient countries in 1961, up from an average of 0.7 in 1961. Levels are generally mixed, with the highest estimates in Uganda and Burundi, suggesting the importance of land quality, availability of water, and labour supply in driving agricultural TFP (Lusigi and Thirtle, 1997). Uganda also has one of the highest rates of growth in TFP, averaging 7.8 percent per year since 1961. For Africa as a whole, TFP grew at an average rate of 1.3 percent per year over the period.

4.2 Data and measurement issues in estimating SSA agricultural productivity

Data on agricultural outputs and inputs are costly to collect. Sub-Saharan African countries have limited budgets devoted to data collection, with the result that data on both conventional and non-conventional inputs are often unavailable or incomplete. For example, in the United States, the definition of conventional inputs has expanded to include pesticides, energy, feed, seeds and intermediate livestock inputs. When an input such as pesticides is left out, increased output that might be attributed to increased pesticide use may be incorrectly attributed to TFP growth instead.

Inadequacies in the international data set for productivity analysis have been pointed out by a number of researchers (Wiggens, 1998; Craig, Pardey and Roseboom, 1997; Trueblood, 1991). To date, most research has concentrated on measuring productivity in new ways with the same existing and insufficient data. Efforts have been made in recent years to improve the data, such as constructing a data set of public agricultural research expenditures by country (Pardey, Roseboom and Anderson, 1989), but much work still needs to be done.

Aggregating agricultural output

In order to aggregate agricultural output for international consistency, output must be measured in a common unit. Typically, output has either been reported in terms of dollars or in terms of “wheat units” (Hayami and Ruttan, 1985; Block, 1995). The wheat units approach was developed by Hayami and Ruttan (1985) and is based on the ratio of each individual commodity price to the price of wheat in India, the United States and Japan. Official exchange rates are generally considered to be a poor choice for converting output in local currency units to dollars due to the biases introduced by fixed exchange rates or sudden devaluations. Most researchers use the purchasing power parity exchange rates inherent in the Food and Agriculture Organization of the United Nations (FAO) international dollar concept. However, Block (1995) argues that wheat units are preferable due to the impact of annual price movements that can affect the agricultural value added to which the international dollar conversions are applied. However, most recent studies have used FAO’s international dollars (Trueblood and Coggins, 1997; Craig, Pardey and Roseboom, 1997).

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[2] Several recent studies have presented Malmquist TFP indexes for various sets of countries (Fulginiti and Perrin, 1997; Lusigi and Thirtle, 1997; Trueblood and Coggins, 1997). The results of Lusigi and Thirtle are presented here, since it is the only study which focuses exclusively and exhaustively on Africa.

Conventional factors of production

Conventional inputs to agricultural production are land, labour, physical capital, livestock and fertilizer. For international comparison studies, the source of most data on these inputs is FAO. Conventional inputs are typically measured in relatively simple physical terms that mask potentially important qualitative variations.

Land is typically measured as hectares of agricultural land, i.e. arable and permanent cropland and permanent pasture (Fulginiti and Perrin, 1997). FAO statistics indicate that Africa had just over one thousand million hectares of agricultural land in 1990, up 0.1 percent annually in the previous two decades (Table 4.2). This measure does not account for land quality. Failure to account for land quality may lead researchers to incorrectly attribute to other inputs differences in production that are actually due to differences or changes in land quality. Some attempts have been made to control for differences in land quality by including a land quality index as a non-conventional input. Such attempts are noteworthy (Craig, Pardey and Roseboom, 1997), but they have been able to apply only one land quality indicator per country. This is problematic for large countries that span several ecozones.

Table 4.2 Levels and trends in African agricultural output and inputs, 1970 – 1990

	Level		Growth rate (percent/year, 1970-1990)
	1970	1990	
Agricultural output (*index, base 1989-1991*)	66	98	2.0
Agricultural land (*millions of hectares*)	1 059	1 090	0.1
Agricultural labour (*millions*)	120	167	1.7
Tractors in use (*thousands*)	334	521	2.2
Cattle (*millions*)	149	188	1.2
Fertilizer consumption (*thousands of tonnes*)	1 615	3 686	4.2

Source: FAO (1999).

The proxy for agricultural labour is often the economically active population in agriculture. Early FAO statistics only included males in the agricultural labour force. More recent data have included both males and females. Table 4.2 shows that Africa's agricultural labour force grew 1.7 percent annually between 1970 and 1990, to 167 million. However, this agricultural labour force variable still does not control for differences across countries in the composition (and thus potentially the quality) of the agricultural labour force by age and education. An additional problem with the FAO data is that the economically active population in agriculture is defined to include workers in agriculture, forestry and fisheries. This implies that the number of workers is overstated for every country, and is more heavily overstated for countries with large forestry and/or fishery sectors relative to their basic agriculture sectors. A few researchers have made attempts to correct for the quality of the agricultural labour force by including national-level measures of education or literacy as non-conventional inputs. No researchers of SSA have adjusted the quality of labour directly by sex, age and education.

Another problem is that many of these economically active agricultural workers are not employed full-time in agriculture. Evidence from Africa suggests that many farmers are heavily involved in off-farm work to supplement their farm incomes (Reardon, Delgado and Matlon, 1992). In such cases, the agricultural labour force may look unduly large and thus bias estimates of labour productivity downwards.

The use of physical capital is typically measured by the stock of tractor horsepower (Hayami and Ruttan, 1985). The number of tractors in use in African agriculture increased 2.2 percent annually between 1970 and 1990, to 521 thousand (Table 4.2). Such a measure is problematic in SSA where many farmers continue to use hand implements, especially in hilly regions where tractors are ill-suited. Farmers' investments in hand hoes, carts, ploughs, fencing, buildings and other locally produced capital inputs have not been accounted for in national and international productivity studies. Incomplete measurement of physical capital, in terms of quality and quantity, will bias productivity estimates. In an effort to improve measurement of physical capital, Craig, Pardey and Roseboom (1997) have updated the physical capital variable to include two- and four-wheel tractors that are converted to horsepower using regional averages.

Livestock is a difficult input to measure since livestock may serve as both an input and an output in agricultural production. As an input, livestock has been measured as the number of livestock on farms at a given point in time (Hayami and Ruttan, 1985). Kawagoe, Hayami and Ruttan (1985) included all livestock as an input, arguing that they represent long-term capital formation in the agricultural sector. Arnade (1997) did not include livestock as an input to production, arguing that in developing countries that do not have meat-processing sectors, livestock is usually sold directly as an output. Craig, Pardey and Roseboom (1997) included livestock as an input, but only included those animals that are primarily used for traction or breeding services. Clearly, differences in how the livestock variable is treated will affect estimates of the levels, sources, and changes in agricultural productivity. Table 4.2 shows a total of 188 million cattle in Africa in 1990, up 1.2 percent annually since 1970.

Commercial fertilizer inputs are measured as tons of nutrient units of nitrogen, phosphorus and potash. FAO data indicate that fertilizer consumed in African agriculture in 1990 totalled 3.7 million tonnes, up 4.2 percent annually since 1970 (Table 4.2). Fertilizer consumption subsequently declined by 1.1 percent per year between 1990 and 1995. However, the fertility benefits of organic sources of nutrients, such as manure and legumes, are not accounted for in this measure. This omission is potentially significant given widespread reliance on organic sources of nutrients in SSA.

Non-conventional factors

Non-conventional factors include private and public agricultural research, education, infrastructure, government programmes and policies, and environmental degradation. Sometimes in an attempt to adjust conventional inputs for quality, researchers have included these variables in the set of non-conventional inputs. Examples include land quality indicators (Frisvold and Ingram, 1995), or proxies for agricultural labour quality, such as literacy and life expectancy (Craig, Pardey and Roseboom, 1997).

At the national level, public agricultural research expenditures are generally used as a proxy for research and development. Public agricultural research expenditures are typically lagged for a number of years to compensate for the time required for research to reach fruition. However, this measure does not account for the spillover of research that is easily transferred from other countries. Private research expenditures have not been included in studies of developing countries since that information has not been collected.

Education is related to the quality of the agricultural labour force. For example, literacy would be expected to improve a farmer's ability to make use of information provided by extension services, or to keep better track of the costs and returns to alternative inputs or marketing opportunities. More generally, a more educated populace may also provide better services to agriculture, improving agriculture's productivity even without changing the quality of the agricultural labour force directly. Since no data are available specifically on the educational level of the agricultural labour force in most countries, national-level proxies are used. Education has been measured by the school enrolment ratio or the adult literacy rate (Hayami and Ruttan, 1985). More generally, the overall quality of the labour force has been measured by national life expectancy (Craig, Pardey and Roseboom, 1997) and by historic calorie availability (Frisvold and Ingram, 1995). In an effort to focus more specifically on the education achievements of the agricultural labour force, Hayami and Ruttan (1985) also looked at the number of agricultural college graduates as a proxy for the level of advanced technical education in agriculture.

Public investments in infrastructure such as roads, utilities, and communications can increase agricultural productivity as well, by lowering the cost of inputs at the farm level and increasing farmers' access to marketing opportunities. Proxy variables include paved road density (Craig, Pardey and Roseboom, 1997) or by gross domestic product of each country's transportation and communication sectors (Hu and Antle, 1993).

Government programmes and policies also affect agricultural productivity. For example, Fulginiti and Perrin (1993) argue that historic agricultural output and input prices affect the technology chosen by farmers, and thus drive observed productivity patterns. Prices may be affected by government policies that tax or subsidize agriculture, and a "net protection coefficient" is used to capture the effect of these policies on agricultural productivity by Hu and Antle (1993) and Fulginiti and Perrin (1997). Block (1995) used depreciation of the real exchange rate as a proxy for government policy reform. The past export growth rate and export instability (Frisvold and Ingram 1995) have also been used as proxies for government policies that might affect productivity. They argue that export growth tends to stimulate overall economic development and productivity growth. They also note that export instability might slow productivity growth.

Researchers have used several variables in an attempt to adjust for the impact of land quality differences on productivity. Several studies have used a land quality index created by Peterson (1987) that indexes land quality at the national level as a function of historic precipitation and the share of a country's land area devoted to pasture and crops. Researchers have also used the percentage of a country's land that is arable, the percentage of land that is irrigated and mean rainfall to adjust for variations in land quality across countries.

Environmental degradation and actions that farmers take to reduce or reverse degradation have been recognized as potentially significant inputs to the production process (Thrupp, 1997), but they have not yet been measured and included as explanatory variables in productivity studies due to the scarcity of nationally or internationally comparable data.

4.3 Existing research on sub-Saharan agricultural productivity

Research on cross-country agricultural productivity comparisons has concentrated on two areas. The first type of studies has estimated econometrically multi-country aggregate or meta-production functions to explain cross-country variation in agricultural productivity and to estimate production elasticities. The second, more recent type of studies has used data envelopment analysis (DEA) to construct Malmquist TFP indices to show which countries are experiencing the highest or lowest rates of growth.

Aggregate production functions

Table 4.3 compares estimated Cobb-Douglas coefficients from studies that estimated separate equations for developed countries (DCs), developing countries (LDCs) and African countries. Kawagoe, Hayami and Ruttan (1985) split their sample of 43 countries into 21 DCs and 22

Table 4.3 Cobb-Douglas aggregate production function estimates (OLS), grouped by developed countries (DCs), developing countries (LDCs) and African countries

	Kawagoe, Hayami & Ruttan (1985)	Kawagoe, Hayami & Ruttan (1985)	Fulginiti & Perrin (1993)	Craig, Pardey & Roseboom (1997)	Frisvold & Ingram (1995)	Lusigi & Thirtle (1997)[a]
years covered	1957-1980	1957-1980	1961-1985	1961-1990	1973-1985	1961-1991
no. of countries	21 DCs	22 LDCs	18 LDCs	67 LDCs	28 African	47 African
no. of African countries	0	1	3	25	28	47
Conventional inputs						
Labour	0.71*	0.56*	0.25*	0.41*	0.59*	0.21*
Land	0.10*	-0.07	0.25*	0.33*		0.19*
Fertilizer	0.19*	0.09	0.18*	-0.01	0.022*	0.16*
Livestock	0.15*	0.32*	0.17*	0.21*	0.18*	0.23*
Machinery	0.18*	0.14*	0.21*	0.06*	0.04*	0.04*
Animal traction hp				-0.02		
Non-conventional inputs						
school enrollment ratio	-0.17	0.41*	0.3*			
technical eduction	0.14*	0.17*				
life expectancy				1.64*		
adult literacy				-0.05		
land quality index			0.51*		0.89*	0.28*
mean rainfall				0.27*		
% land arable				0.35*		
% land (not) irrigated				-0.37*	0.45*	
research expenditures			-0.02	0.09*	0.09	0.03*
infrastructure				0.48		
past output price			0.13*			
past wages			-0.09*			
past fertilizer price			0.03			
export growth					0.03*	
export instability index					0.0004	
calorie availability					0.35*	
Dummy variables						
time (t+1)	0.09	-0.22*				0.0004*
time (t+2)	0.17*	-0.43*				
sum of conventional Coefficients	1.32	1.04	1.06			0.83

[a] This study used corrected ordinary least squares.
* indicates significance at the 0.05 level.

LDCs. They found all the conventional variables as well as technical education to be important in explaining output levels for the DCs. For the LDCs, land and fertilizer were not found to be significant explanatory variables, but livestock was more important when compared to the DCs. In addition, both the school enrolment ratio and technical education were found to be significant. Summing over the coefficients of conventional inputs, Kawagoe, Hayami and Ruttan found increasing returns to scale in the DCs and constant returns to scale in the LDCs. They explain that an increasing substitution of large machines for labour has led to the pattern of increasing returns to scale observed in DC agriculture. On the other hand, they argue that many of the productivity increases realized in LDC agriculture have come from the increased use of high-yielding seed varieties and fertilizer, which are scale-neutral. They conclude that there is still much scope in LDC agriculture to increase productivity, and in particular labour productivity, by increasing investment in education, research, and modern inputs.

Fulginiti and Perrin (1993) conducted a study of 21 countries that included three African countries. They were particularly interested in examining how past pricing policies affected technology choice and thus current agricultural productivity. In addition to conventional inputs, they included past output prices, past wages and past fertilizer prices as well as the school enrolment ratio, a land quality index and research expenditures as non-conventional inputs. They found all of the conventional inputs to be significant as well as fairly close to the range of estimates found in other studies, except for land, which had a larger coefficient (0.25). They argued that previous studies, which did not include country-specific effects such as the land quality index used in their study, tended to bias the land elasticity downward. Higher school enrolment ratios are associated with higher productivity. The coefficient on the past output price variable was 0.13, indicating that a one percent change in past output price expectations would lead to a 0.13 percent shift in the production function. Echoing Hu and Antle's (1993) study of non-African countries, they argue that eliminating policy interventions that tax agriculture would increase productivity, while elimination of subsidies would decrease productivity.

Fulginiti and Perrin (1993) also estimated productivity increases that would be possible from eliminating output price policies that tax agriculture. The estimated productivity increases associated with such policy reforms ranged from 1.4 percent in Colombia to 129 percent in Zambia. Côte d'Ivoire and Ghana had estimated productivity increases of 88 percent and 16 percent, respectively. Fulginiti and Perrin tried several different formulations of the research expenditure variable, and found it to be significant only when measured as the work-years of government agricultural research, cumulated into a stock using a five-year lag. The sensitivity of these results with respect to different variable specifications reinforces the importance of measurement issues in evaluating agricultural productivity.

Frisvold and Ingram (1995) estimated land productivity for 28 countries in sub-Saharan Africa between 1973-1975 and 1983-1985. They estimated land productivity grew at an annual rate of 1.5 to 1.8 percent in most regions over the period. All conventional inputs were found to be significant, and the coefficient on labour was particularly large at 0.59. Frisvold and Ingram found that increased application of agricultural labour was the single most important factor in explaining growth in land productivity, and concluded that substantial increases in land productivity should not be expected until land becomes relatively scarce, echoing Binswanger and Pingali (1988) and Boserup (1965). They also found land quality, as measured by the Peterson (1987) index, to be an important explanatory variable, as was the percentage of area irrigated. Similar to Fulginiti and Perrin (1993), they did not find research expenditures to be significant. However, they did show that export growth and historic calorie availability have contributed positively to productivity growth in SSA. Growth in the stock of conventional inputs as a whole accounted for more than two thirds of growth in land productivity, which in turn accounted for the majority of growth in agricultural output.

Lusigi and Thirtle (1997) used a sample of 47 countries in Africa over the period 1961-1991. They estimated an average rate of TFP growth of 1.3 percent per year over that time period. Livestock, labour and land are the most important inputs explaining variation in productivity across the countries, with population pressure (and thus expansion of the agricultural labour force) an important factor driving productivity growth. Fertilizer and machinery are significant but of less importance. Like Frisvold and Ingram (1995), Lusigi and Thirtle stressed the contribution of population pressure to faster growth, arguing that land abundance depresses farmer incentives to increase land productivity by adopting yield-increasing technologies. They also found land quality and research expenditures to be important explanatory variables.

While the significance of specific inputs varies across studies using the production function approach, these studies have found in general that increased use of conventional inputs, especially those other than land, are the most important factors in explaining growth in agricultural productivity and output. Studies that have included measures of infrastructure and of land and labour quality have shown that variation in those factors is also important. The estimated effect of research on agricultural productivity varies by region studied, how the research variable is specified, and on the lag length selected.

The Malmquist index

A traditional Tornqvist TFP index, which requires data on input prices and is used for calculating agricultural productivity in the United States, has never been constructed for SSA or used in multi-country production studies because the required data are not available. Instead, studies of agricultural productivity in SSA have used either a production function approach or a Malmquist TFP index, neither of which requires data on input prices. The Malmquist TFP studies are relatively new and have provided some insight into the relative ranking of countries in terms of productivity. However, researchers have not yet attempted to explain the differences in productivity across countries.

Data envelopment analysis (DEA) for creating Malmquist indexes of total factor productivity is a non-parametric programming approach that uses data on physical inputs and outputs to model efficiency levels. DEA identifies the best-practice countries out of a set of countries under study. The best-practice countries are those which minimize inputs per unit of output. Those countries then define the efficient production frontier. The efficiency of all other countries under study is measured relative to that efficient production frontier. Technical change is determined by the position of a country relative to the changing position of the efficient frontier over time.

Since the efficient production frontier depends on the set of countries included in the study, the productivity growth rates calculated by each study will depend on the countries included in the analysis. For example, Table 4.4 compares the TFP growth rates calculated from Malmquist indexes for selected SSA countries included in three different studies. Lusigi and Thirtle (1997) calculated the Malmquist TFP growth rates based on a set of 47 African countries for the period 1961-1991. Trueblood and Coggins (1997) constructed their Malmquist TFP growth rates by analysing 117 countries from all world regions for 1962-1990. Thirtle, Hadley and Townsend (1995) estimated growth rates for 22 SSA countries over the period 1971-1986.

The differences in results due to the selection of countries and time periods are striking. Relative to the efficient frontier for Africa alone, Lusigi and Thirtle (1997) show that the majority of SSA countries had positive TFP growth rates. Zaire, Uganda, Rwanda and Burundi (3.4 to 8.1 percent per year) achieved the highest rates of growth. In comparison, Trueblood and Coggins (1997) showed negative TFP growth rates for most SSA countries over the period 1962-1990 when they were compared to a global set of countries encompassing a much wider range of technologies, suggesting the technology gap between Africa and the rest of the world is widening. The ranking of SSA countries with positive growth rates were Congo (Brazzaville), South Africa, Uganda, Benin, Sierra Leone and the Central African Republic. Two of the highest-ranking countries in the study by Lusigi and Thirtle (1997), Rwanda and Burundi, had nearly the lowest growth rates of TFP in the worldwide study (-13.9 and -16.4 percent, respectively). Thirtle, Hadley and Townsend (1995) find low but positive TFP growth rates for most of the 22 SSA countries they studied for 1971-1986, with the highest rates in Rwanda and Burundi.

Thirtle, Hadley and Townsend (1995) decompose the Malmquist TFP growth rates they find for 22 SSA countries into technical progress (from the time series for this panel of countries) and efficiency changes (from the cross-section). Investments in infrastructure, extension and the level of real protection on international agricultural markets are shown to be significant in

Table 4.4 Comparisons of Malmquist TFP growth rates for African countries

	Lusigi & Thirtle (percent/year, 1961-91)	Trueblood & Coggins (percent/year, 1962-90)	Thirtle, Hadley & Townsend (percent/year, 1971-86)
Central Africa			
Cameroon	1.8	-2.8	1.0
Central African Republic	2.7	0.0	1.8
Congo	1.2	1.6	-1.4
Gabon	-2.3	-25.8	na
Zaire	8.1	-2.1	1.5
East Africa			
Burundi	3.4	-16.4	2.7
Ethiopia	-1.7	-2.5	0.7
Kenya	1.9	-0.2	0.6
Madagascar	-0.1	-5	na
Rwanda	6.1	-13.9	3.2
Uganda	7.8	1.2	na
Sahel			
Burkina Faso	0.8	-4.6	1.6
Chad	0.2	-2.5	na
Gambia	-1.5	na	na
Mali	0.8	-4.1	2.2
Mauritania	-0.3	-12.3	na
Niger	1.5	-5.7	na
Senegal	1.5	-3.4	-0.0
Somalia	1.2	-0.3	-0.3
Sudan	0.1	-2.5	-0.3
West Africa			
Benin	1.2	0.8	na
Côte d'Ivoire	0.9	-1.0	1.3
Ghana	-0.5	-2.5	0.6
Guinea	1.2	-1.7	na
Guinea-Bissau	-2.1	na	na
Liberia	0.0	-4	na
Nigeria	-0.3	-4.7	1.0
Sierra Leone	0.5	0.4	0.3
Togo	-1.3	-6.4	0.1
Southern Africa			
Angola	-0.8	-3.2	na
Botswana	1.3	-0.1	na
Lesotho	-1.7	-2.7	na
Malawi	0.3	-3.1	0.6
Mozambique	0.3	-1.0	na
Namibia	1.0	na	na
South Africa	1.3	1.5	na
Swaziland	3.3	na	na
Tanzania	0.2	-3.0	2.0
Zambia	1.5	-1.9	-1.0
Zimbabwe	2.0	-0.4	0.3

Sources: Lusigi & Thirtle (1997); Trueblood & Coggins (1997); Thirtle, Hadley & Townsend (1995).

explaining efficiency change, while tractors, the labour-land ratio, R&D and secondary education are found to explain the variation in technical progress. They find the labour-land ratio, or population density, to be the single most important explanatory variable, again suggesting that productivity growth will accelerate in land abundant countries as population density increases.

Growth accounting

Paralleling the two types of productivity studies, aggregate production function and TFP indexes, are two types of growth accounting exercises. In the first case, the coefficients from the aggregate

Cobb-Douglas production function are used to calculate the percentage growth in output due to changes in the level of each input. Changes in the residual or TFP are attributed to non-conventional factors.

Arnade (1997) conducted this exercise for a set of 77 countries, including five in Africa (Kenya, South Africa, Sudan, Zaire and Zimbabwe). He included livestock as a conventional factor only in Asia, where bullocks are commonly used for ploughing. He did not include livestock as a factor of production in other regions, arguing that there is little meat processing in the developing countries so livestock is sold as an output. For the Cobb-Douglas coefficients, Arnade used 0.20 for labour, 0.45 for land, 0.15 for fertilizer, and 0.20 for tractors. Constant coefficients such as these are consistent with marginal factor productivities that may vary with input levels across countries and across time. Arnade's coefficients are within the range of estimates found in the empirical studies reported in Table 4.3, except for the coefficient on land, which is larger than those found in other studies. This is likely due to the exclusion of livestock from the aggregate production function.

Results from Arnade's study for the five African countries and a representative sample of other countries are reported in Table 4.5. As expected, during the period 1961-1987, the growth rate of productivity was much higher in the "advanced technology" countries than in Africa or Asia. In the advanced technology countries, the level of land and labour inputs dropped while output increased, due mainly to increased fertilizer use and improvements in productivity. In the Asian countries reported, the contribution of land expansion to output growth was low, while tractor use showed a high rate of increase. The growth rate of labour and fertilizer was moderate, while productivity growth was mixed. For the African countries, the increases in agricultural land were relatively small, while increases in labour, tractor, and fertilizer use contributed significantly to output growth.

The differences between Asia and Africa and the advanced technology countries are stark. The latter have been able to maintain increases in agricultural output while decreasing labour and land inputs. Asia and Africa have relied much more heavily on increases in the conventional inputs. This is hardly surprising, given their relatively low levels of conventional input use, other than labour and land. For Africa, excluding South Africa (because of its advanced agricultural technology relative to the rest of SSA) and Zambia (due to its negative growth rate of productivity), growth in the use of conventional inputs explains approximately 60 to 80 percent of the growth in agricultural output over the period under study.

Most of the studies reviewed above that calculated aggregate Cobb-Douglas production functions did not go on to perform a growth accounting exercise. However, Craig, Pardey and Roseboom (1997) noted that the conventional inputs in their equation accounted for 72 percent of the variation in productivity, both for LDCs alone and also when DCs were included. Frisvold and Ingram (1995) did perform an in-depth growth accounting study for their sample of 27 SSA countries. For three of the four SSA regions under study (the Semi-Arid Tropics, the Sub-Humid Tropics and the Humid Tropics), they found that conventional inputs explained 84 to 93 percent of the increase in agricultural output. For the Lowland Humid Tropics (which consisted only of Mauritius and Madagascar) the figure was only 22 percent.

Projections of future growth in African agricultural production

A number of research efforts have generated projections of future growth in agricultural production in SSA. For example, FAO projects that gross agricultural production in SSA will increase at an average annual rate of three percent between 1988-1990 and 2010 (FAO, 1993). Of this increase, 53 percent is projected to come from increases in yield, 30 percent from increases in arable land, and 17 percent from increases in cropping intensity. The International

Table 4.5(a). Contributions to average rates of output growth, based on coefficients from an aggregate Cobb-Douglas production function, 1961-1987 (growth rates in percent per year)

Country	Output	Labour	Land	Tractors	Fertilizer	Productivity	Animals
C-D coefficients		0.20	0.45	0.20	0.15		
Africa							
Kenya	2.81	0.67	0.13	0.32	1.09	0.60	
South Africa	2.14	-0.19	-0.10	0.31	0.78	1.34	
Sudan	3.05	0.39	0.05	0.92	0.53	1.15	
Zaire	2.03	0.18	0.07	0.91	0.17	0.71	
Zambia	2.40	0.44	0.02	0.99	1.45	-0.49	
Zimbabwe	2.67	0.46	0.18	0.29	0.68	1.05	
Asia							
China	4.10	0.35	-0.03	2.40	0.05	1.27	0.06
India	2.50	0.28	0.05	2.34	1.31	-1.44	-0.04
Indonesia	3.80	0.14	0.18	2.60	0.37	0.46	0.05
Philippines	3.44	0.32	0.36	1.26	0.50	1.05	-0.06
Advanced technology							
Australia	2.16	-0.15	-0.05	0.12	0.23	2.02	
France	1.66	-0.83	-0.15	0.49	0.47	1.65	
United Kingdom	1.60	-0.34	-0.11	0.11	0.36	1.58	
United States	1.85	-0.41	-0.03	-0.05	0.45	1.89	

Source: Arnade (1997).

Table 4.5(b). Contributions to average rates of output growth, based on coefficients from an aggregate Cobb-Douglas production function, 1961-1987 (percentage of output growth due to each factor)

Country	Output	Labour	Land	Tractors	Fertilizer	Productivity	Animals
C-D coefficients		0.20	0.45	0.20	0.15		
Africa							
Kenya	2.81	23.8	4.6	11.4	38.8	21.4	
South Africa	2.14	-8.9	-4.7	14.5	36.4	62.6	
Sudan	3.05	12.8	1.6	30.2	17.4	37.8	
Zaire	2.03	8.9	3.4	44.8	8.4	35.0	
Zambia	2.40	18.3	0.8	41.3	60.4	-20.4	
Zimbabwe	2.67	17.2	6.7	10.9	25.5	39.3	
Asia							
China	4.10	8.5	-0.7	58.5	1.2	31.0	1.5
India	2.50	11.2	2.0	93.6	52.4	-57.6	-1.6
Indonesia	3.80	3.7	4.7	68.4	9.7	12.1	1.3
Philippines	3.44	9.3	10.5	36.7	14.5	30.5	-1.7
Advanced technology							
Australia	2.16	-6.9	-2.3	5.6	10.6	93.5	
France	1.66	-50.0	-9.0	29.5	28.3	99.4	
United Kingdom	1.60	-21.3	-6.9	6.9	22.5	98.8	
United States	1.85	-22.1	-1.6	-2.7	24.3	102.2	

Source: Arnade (1997).

Food Policy Research Institute projects similarly strong growth in grain production in SSA, averaging three percent annually between 1990 and 2020 (Rosegrant, Agcaoili-Sombilla and Perez, 1995). Area in cereals is projected to increase 1.3 percent annually over the period, and yields are projected to increase 1.7 percent per year. World Bank simulations for selected developing countries include projections of 2.5 percent annual growth in grain production in Central Africa between 2000 and 2010, and 1.5 in Nigeria and South Africa, from a combination of yield and area increases (Mitchell and Ingco, 1995). The USDA's Economic Research Service (Shapouri and Rosen, 1998) projects that food production in SSA will grow at an average rate of 2.3 percent per year between 1995-1997 and 2008 through a combination of area expansion (1.3 percent per year) and yield increases (1.0 percent per year).

4.4 Bottlenecks to growth

The studies reviewed provide a guide to the factors that have historically affected agricultural productivity in SSA. Since conventional inputs explain most of the variation in productivity between countries in SSA, it is apparent that many of these countries still have considerable potential to raise productivity through increased use of fertilizer, machinery and livestock inputs. It has been argued that barriers to increased use of these inputs include lack of appropriate infrastructure, poor policy environments, and lack of cash to increase input purchases (Byerlee and Heisey, 1996; Heisey and Mwangi, 1996; Larson and Frisvold, 1996).

The importance of conventional inputs in SSA suggests that factors limiting their use are the most critical constraints on continued growth in agricultural productivity. Foremost among these are inadequacies in the provision of basic infrastructure, both physical and institutional. For example, limited surface transportation and communication networks in SSA increase the cost of inputs, inhibit the timely acquisition and application of inputs, and decrease access to output markets. Examples of institutional bottlenecks with similar effects include elements as diverse as political instability and constraints on access to credit and extension services. Credit market constraints are in turn driven, at least in part, by the complexities of land tenure that characterize much agricultural land in SSA. In particular, lack of individual private tenure and associated land titles as collateral may inhibit access to formal credit sources, even though customary tenure systems may offer no less security than individual private property systems (Bruce and Migot-Adholla, 1994).

Even more basic than concerns about physical and institutional infrastructure, however, are questions about the potential for continued increases in application of the conventional inputs that have contributed to growth in SSA agricultural productivity in the past. For example, Crosson and Anderson (1995) report that just over one billion hectares of land are considered by FAO to be at least marginally suitable for crop production in SSA. About 213 million hectares, or just over a fifth of that, are currently in crops. Crosson and Anderson note that if all the remaining suitable land were to be brought under crop production in the coming decades, output would increase more than enough to meet a tripling in demand by 2025, even without any increase in crop yields. Expansion on such a scale is of course unlikely, as the authors argue, because of the economic and environmental costs involved. In fact, FAO (1993) estimates that cropland area in SSA will expand by 0.9 percent per year over the next decade, which, if continued, would result in a 37 percent expansion by 2025. By contrast, the World Bank suggests that 0.5 percent annual expansion may be the maximum rate consistent with long-term sustainability (Cleaver and Schreiber, 1994).

Given the importance accorded to physical infrastructure and education as non-conventional inputs in other multi-country studies of agricultural productivity as well (Craig, Pardey and Roseboom, 1997; Antle, 1983), it is surprising that these variables have not been included in the studies exclusive to Africa. It may be that data on infrastructure are not available for a sufficiently large set of African countries. In addition, the sequence of non-conventional inputs may be important. A study of agricultural productivity in the US has shown that infrastructure investments made important contributions to agricultural productivity through the 1960s (Shane, Roe and Gopinath, 1998). Since that time, however, public and private R&D have become more important in spurring productivity growth in the United States. If a similar trend holds for countries where infrastructure is not yet well developed (as in much of Africa), large increases in agricultural productivity may be possible from investments in rural roads and utilities.

Other variables that deserve closer attention in studies of agricultural productivity include changes in resource quality over time and measures of political and institutional instability. Messer, Cohen and D'Costa (1998) estimated that cessation of armed conflict would have added two to five percent annually to Africa's per caput food production since 1980. Peterson's

(1987) useful land quality index, which controls for irrigation, precipitation and soil nitrogen, has been used frequently in international agricultural empirical work, but provides only one (constant) number per country that fails to reflect possible changes in land quality over time. If a portion of growth in agricultural output is actually due soil fertility depletion, but soil depletion is left as an unmeasured explanatory variable, then growth in output may be incorrectly attributed to productivity growth.

Based on the limited data currently available on land degradation and its productivity consequences in SSA, Crosson and Anderson (1995) estimate the average loss in agricultural productivity due to historic land degradation for Africa as a whole is about 12 percent. The authors conclude that land expansion and restoration will together contribute only about a third of the increased production necessary to meet anticipated demand in 2025. They caution that the potential for increased water supply is too limited to make a major contribution to increased production.

Crosson and Anderson argue that the remainder of the necessary production increases will have to come from adoption of a variety of more productive technologies, including improved crop varieties, increased use of fertilizer and pesticide and mechanization. Policies that will help widespread adoption of such technologies include reform of foreign exchange and tax policies that discriminate against agriculture, improvement of transportation and communications infrastructure, improved education and extension services, support for research and increased recognition of the security of property rights in land afforded by evolving local tenure systems.

Following Pingali and Heisey (1996), the technological transformation of crop production systems can be characterized in various stages, as different factors of production become scarce in succession. Pingali and Heisey describe three stages in particular with regard to cereal production, as land, labour and factors such as knowledge and management intensity become increasingly valuable. Thus, cropland expansion alone will no longer satisfy needed output growth, and further increases will need to come from intensification of production on existing cropland. Such intensification will require investment not just in basic transportation infrastructure but in the physical and institutional infrastructure necessary to improve delivery of irrigation, commercial fertilizer, extension services and other conventional and non-conventional inputs (Pingali and Heisey, 1996). Pingali and Heisey argue that for maize, an important food crop in much of SSA, there remains an economically exploitable gap between farmer performance and the technology frontier as represented by the yields achieved on experiment stations (in contrast to rice and wheat yields). They argue further that the technology frontier itself could be shifted more readily for maize than for rice or wheat, through transfer of technology from the more advanced countries. They caution, however, that such transfers are much less likely in SSA than in parts of Asia, where rising feed demand coincides with institutional environments that are more attractive to large private-sector seed companies.

4.5 The role of policy

Agriculture in SSA is characterized by multiple constraints on accelerated productivity growth. In the absence of broad improvements in physical infrastructure, political stability and the institutional environment, the returns to any given intervention in isolation are likely to be limited as other constraints quickly become binding. In such an environment, the role of policy is twofold.

First, governments and international agencies need to invest in underlying physical and institutional infrastructure to improve the basic performance of markets by reducing the costs of transportation and transactions and by facilitating the transmission of goods, services and market signals. Improved access to fertilizer, credit and roads are among the most promising steps that could be taken along these lines. Such improvements can be expected to reduce input costs and increase access to output markets, providing both demand- and supply-side incentives for increased use of conventional inputs and output growth.

Even when markets can be structured to perform more efficiently, a second role of policy remains critical. This is the mitigation of externalities. For example, reduced fallow periods by one farmer might pose erosion problems that result in sedimentation or increased flood risk to producers downstream, or in eventual on-site resource degradation that threatens farm yields in the future. Externalities highlight the importance of well-defined institutions governing property and the distribution of costs and benefits associated with various technical and institutional innovations. They also highlight the importance of policy in influencing how these costs and benefits are distributed spatially and temporally. Hazell and Fan (1998) note the importance of investing in measures to improve productivity not only in prime agricultural areas but in less-favoured lands as well. Their results are based on analysis of Indian data; additional research is needed to determine whether similar patterns may characterize sub-Saharan Africa.

Several of the studies reviewed above looked explicitly at policy reform as an explanation for productivity growth, focusing particularly on institutional reforms that affect the performance of markets. Block (1995) found that countries that depreciated the real exchange rate tended to have higher growth rates of total factor productivity. Fulginiti and Perrin (1997) used nominal price protection as a proxy for policy reform and concluded that the countries that tax agriculture the most tend to have the most negative rates of productivity change. Fulginiti and Perrin (1993) and Hu and Antle (1993) found that an indicator of the degree of subsidization or taxation of agriculture is significant in some ranges; reducing protection would increase (decrease) productivity in countries that have been taxing (subsidizing) agriculture.

4.6 Conclusions

Agricultural production has been increasing in SSA at over two percent per year in recent years (FAO, 1999). Land used in agricultural production has increased less rapidly, resulting in an average annual increase in land productivity of 1.9 percent in SSA between 1980 and 1993 (World Bank, 1998). Labour used in agriculture has increased more rapidly than land and labour productivity declined at an average annual rate of 1.0 percent between 1980 and 1995 (World Bank, 1998). Levels of physical capital, livestock, fertilizer and non-conventional inputs have also changed, contributing to an estimated 1.3 percent annual increase in total factor productivity between 1961 and 1991 (Lusigi and Thirtle, 1997).

Existing research has consistently found that about three-quarters of the variation in agricultural productivity in SSA is explained by the use of conventional inputs. This is not surprising, given the low levels of use of some conventional inputs in SSA, such as physical capital and fertilizer, relative to other developing regions and the developed countries. As a result, research suggests that there remains significant scope to improve productivity in many SSA countries through increased use of conventional inputs, particularly fertilizer, physical capital and livestock.

Based in part on such improvements in productivity, several recent research efforts have generated projections of future growth in agricultural production in SSA. FAO projects agricultural production will increase at an average annual rate of 3.0 percent between 1988-1990 and 2010, driven primarily by increases in yield (FAO, 1993; Alexandratos, 1995). The International Food Policy Research Institute projects 3.0 percent growth in grain production annually between 1990 and 2020, also due primarily to yield increases (Rosegrant, Agcaoili-Sombilla and Perez, 1995). The World Bank projects annual rates of growth in grain production of 1.5 to 2.5 percent for selected SSA countries between 2000 and 2010 (Mitchell and Ingco, 1995). The USDA's Economic Research Service (Shapouri and Rosen, 1998) projects that food production in SSA will grow at an average rate of 2.3 percent per year over the next decade through a combination of area expansion (1.3 percent per year) and yield increases (1.0 percent per year).

The ERS analysis further projects that food production in SSA would have to grow at a rate of 3.3 to 4.5 percent annually to maintain per caput consumption levels or meet nutritional requirements over the next decade. Given projected production increases on the order of 2.3 to 3.0 percent per year, these rates suggest that additional increases on the order of one to two percent per year will be required to make progress towards food security. If the World Bank's recommendation (Cleaver and Schreiber, 1994) that agricultural area expansion in SSA be limited to 0.5 percent per year on sustainability grounds is further incorporated, this gap increases to two to three percent per year.

How might such gains be realized? The studies reviewed above on the sources of productivity growth in SSA agriculture indicate that continued growth of the agricultural labour force on the order of two percent per year (FAO, 1999) can be expected to increase agricultural output by about one percent per year. As land becomes increasingly scarce relative to labour, farmers will increasingly seek ways to augment land through increased application of other inputs as well. Fertilizer application rates have been declining in Africa by an average of 1.1 percent per year since 1990 (FAO, 1999); reversing this trend and increasing fertilizer use by five percent per year could increase agricultural output by an additional 0.5 percent per year. Proportionate increases in the use of machinery and in research expenditures could be expected to add similar increases to output. Expected increases in output from improved infrastructure and price policies are difficult to quantify, but such improvements are probably prerequisites to make possible the increases in productivity from the use of conventional inputs and research.

Achieving these goals poses significant challenges for policymakers. Agriculture in SSA is characterized by multiple constraints, principal among which are poverty, poor infrastructure and political instability, which combine to limit increased use of conventional inputs in SSA agriculture. Other important constraints to agricultural productivity are the quality and availability of education, research and extension services, as well as institutional uncertainties that weaken incentives to invest in the maintenance or improvement of land quality.

In the absence of broad improvements in physical infrastructure, political stability and the institutional environment, the returns to any given intervention in isolation are likely to be limited as other constraints quickly become binding. Policy reforms directed at improving physical and institutional infrastructure may not only increase use of inputs by lowering prices, but may also improve farm-gate prices of agricultural output and thus more directly stimulate output.

In addition to facilitating increased use of conventional inputs, education of the rural labour force as well as agricultural research will improve the future prospects for productivity growth in SSA. The full benefits of research are unlikely to be realized before more basic constraints are surmounted. Nevertheless continued investment in research (alongside attention to more basic sources of productivity growth) remains important due to potentially long lags in application.

References

Alexandratos, N. 1995.. The outlook for world food and agriculture to year 2010. *In* Nurul Islam,ed. *Population and food in the early twenty-first century.* Washington, DC, International Food Policy Research Institute.

Antle, J. M. 1983. Infrastructure and aggregate agricultural productivity: international evidence. *Economic Development and Cultural Change,* 31(3):609-619.

Arnade, C.A. 1997. *Agriculture growth sources: a look at 77 countries*, Staff Paper No. 9709. Washington, DC, US Department of Agriculture, Economic Research Service

Badiane, O. & Delgado, C. 1995. *A 2020 vision for food, agriculture, and the environment in Sub-Saharan Africa*. Food, Agriculture, and the Environment Discussion Paper 4. Washington, DC, International Food Policy Research Institute.

Binswanger, H. & Pingali, P. 1988. Technological priorities for farming in Sub-Saharan Africa. *World Bank Research Observer,* 3: 81-98.

Block, S.A. 1995. The recovery of agricultural productivity in Sub-Saharan Africa. *Food Policy,* 20(5):385-405.

Boserup, E. 1965. *The conditions of agricultural growth: the economics of agrarian change under population pressure*. London, George Allen & Unwin.

Bruce, J.W. & Migot-Adholla, S.E. 1994. *Searching for land tenure security in Africa*. Dubuque, Iowa, USA, Kendall-Hunt, for the World Bank.

Byerlee, D. & Heisey, P.W. 1996. Past and potential impacts of maize research in sub-Saharan Africa: a critical assessment. *Food Policy,* 21(3):255-277.

Cleaver, K.M. & Schreiber, G.A. 1994. *Reversing the spiral: the population, agriculture, and environment nexus in Sub-Saharan Africa.* Washington, DC, The World Bank,

Craig, B.J., Pardey, P.G. & Roseboom, J. 1997. International productivity patterns: accounting for input quality, infrastructure and research. *American Journal of Agricultural Economics,* 79(November):1064-1076.

Crosson, P. & Anderson, J.R. 1995. *Achieving a sustainable agricultural system in Sub-Saharan Africa*. World Bank, Building Blocks for Africa 2025 Paper No. 2. March.

FAO. 1999. FAOSTAT Database. Http://apps.fao.org. Accessed 23 March 1999.

FAO. 1993. *Agriculture: towards 2010.* Rome.

Frisvold, G. & Ingram, K. 1995. Sources of agricultural productivity growth and stagnation in Sub-Saharan Africa. *Agricultural Economics,* 13:51-61.

Fulginiti, L.E. & Perrin, R.K. 1993. Prices and productivity in agriculture. *The Review of Economics and Statistics,* 75(August, no. 3):471-482.

Fulginiti, L.E. & Perrin, R.K. 1997. LDC agriculture: nonparametric Malmquist productivity indexes. *Journal of Development Economics,* 53:373-390.

Hayami, Y. & Ruttan, V.W. 1985. *Agricultural development: an international perspective*. Baltimore, USA. The Johns Hopkins University Press.

Hazell, P. & Fan, S. 1998. Balancing regional development priorities to achieve sustainable and equitable agricultural growth. Washington, DC, International Food Policy Research Institute. Prepared for the AAEA International Conference on Agricultural Intensification, Economic Development, and the Environment, July 31-August 1, Salt Lake City.

Heisey, P.W. & Mwangi, W. 1996. *Fertilizer use and maize production in Sub-Saharan Africa.* CIMMYT Economics Working Paper 96-01. Mexico, D.F., International Maize and Wheat Improvement Center (CIMMYT).

Hu, F. & Antle, J.M. 1993. Agricultural policy and productivity: international evidence. *Review of Agricultural Economics,* 15(September, no. 3):495-505.

Kawagoe, T., Hayami, Y. & Ruttan, V.W. 1985. The intercountry agricultural production function and productivity differences among countries. *Journal of Development Economics,* 19(Sept-Oct):113-132.

Larson, B.A. & Frisvold, G.B. 1996. Fertilizers to support agricultural development in Sub-Saharan Africa: what is needed and why. *Food Policy,* 21:509-525.

Lusigi, A. & Thirtle, C. 1997. Total factor productivity and the effects of R&D in African agriculture. *Journal of International Development,* 9(4): 529-538.

Messer, E., Cohen, M.J. & D'Costa, J. 1998. Food from peace: breaking the links between conflict and hunger. 2020 Brief 50. Washington, DC, The International Food Policy Research Institute.

Mitchell, D.O. & Ingco, M.D. 1995. Global and regional food demand and supply prospects. In N. Islam, ed. *Population and Food in the Early Twenty-First Century*. Washington, DC, International Food Policy Research Institute.

Pardey, P., Roseboom, J. & Anderson, J. 1989. *Agricultural research policy: international quantitative perspectives*. Cambridge, UK: Cambridge University Press.

Peterson, W. 1987. *International land quality indexes.* Department of Agricultural and Applied Economics Staff Paper P87-10, University of Minnesota.

Pingali, P.L. & Heisey, P.W. 1996. Cereal crop productivity in developing countries: past trends and future prospects. *Conference Proceedings, Global Agricultural Science Policy for the Twenty-First Century*, Melbourne, Australia, 26-28 August.

Reardon, T., Delgado, C. & Matlon, P. 1992. Determinants and effects of income diversification amongst farm households in Burkina Faso. *Journal of Development Studies,* (January).

Rosegrant, M.W., Agcaoili-Sombilla, M. & Perez, N.D. 1995. *Global Food Projections to 2020: Implications for Investment*. Food, Agriculture, and the Environment Discussion Paper No. 5. Washington, DC, International Food Policy Research Institute.

Rosen, S. 1997. Sub-Saharan Africa. *In* S. Shapouri & S. Rosen, eds. *Food Security Assessment*. International Agriculture and Trade Report No. GFA-9, Economic Research Service, US Department of Agriculture (November), Washington, DC.

Shane, M., Roe, T. & Gopinath, M. 1998. *US agricultural growth and productivity: an economywide perspective*. Market and Trade Economics Division, Economic Research Service, US Department of Agriculture, Washington, DC. Agricultural Economic Report No. 758.

Shapouri, S. & Rosen, S., eds. 1998. *Food security assessment*. International Agriculture and Trade Report No. GFA-10. Economic Research Service, US Department of Agriculture, Washington, DC.

Thirtle, C., Hadley, D. & Townsend, R. 1995. Policy induced innovation in Sub-Saharan African agriculture: a multilateral Malmquist productivity index approach. *Development Policy Review*, 13(4): 323-342.

Thrupp, L.A. 1997. *Linking biodiversity and agriculture: challenges and opportunities for sustainable food security*. Washington, DC, World Resources Institute.

Trueblood, M.A. 1991. *Agricultural production functions estimated from aggregate intercountry observations: a selected survey*. Agriculture and Trade Analysis Division, Economic Research Service, US Department of Agriculture, Washington, DC. Staff Report No. AGES 9132.

Trueblood, M.A. & Coggins, J. 1997. Nonparametric estimates of intercountry agricultural efficiency and productivity. Economic Research Service, US Department of Agriculture, Washington, DC. Mimeo.

Wiggens, S. 1998. African farming seen from village studies: changes from the 1970s to the 1990s. Paper for the ASA-Supported Conference on Africa and globalisation: towards the millennium, University of Central Lancashire at Preston, 24-26 April 1998.

World Bank. 1998. *World development indicators 1998.* Washington, DC, The World Bank.

5. Agricultural productivity for sustainable food security in Asia and the Pacific: the role of investment

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The focus of this chapter is on improving productivity and food availability as the first step towards sustainable food security in Asia and the Pacific. The overall purpose of this study is to determine how to promote agricultural productivity growth to achieve sustainable food security most efficiently in Asia and the Pacific. The specific objectives are: 1) to examine the trends in agricultural production and productivity growth in Asia and the Pacific; 2) to isolate the sources of agricultural productivity growth; and 3) to determine the relative significance of these factors in determining the success in agriculture of member countries. Special attention is paid to the role of investment, both in physical and human capital, in maintaining and increasing agricultural productivity. The analysis provides policy implications useful for improving food security.

5.1 Introduction

Ensuring food for all, today and in generations to come, is one of the greatest challenges facing the world community. Food security is defined as the ability of people to meet their required level of food consumption at all times; it is considered by many to be a basic human right. However, about 1.1 thousand million people in low-income, food-deficit developing countries cannot meet such basic needs (FAO, 1997a). Among them, more than 800 million live in rural areas, depending directly on agriculture for their food supply, employment and income. Therefore, boosting the rural economy, particularly through increased agricultural production, is one of the chief means of alleviating poverty and increasing food security (Pinstrup-Andersen and Pandya-Lorch, 1998).

Food security consists of three major components: availability (associated with production and trade); accessibility (associated with income and wealth); and utilization (associated with health and nutrition) (Asenso-Okyere, Benneh and Tims, 1997). While there seems to be a consensus among analysts that current global food production is adequate to avoid widespread famine and malnutrition (Rosegrant and Ringler, 1997), the overall positive trends disguise the disparities in production and distribution of food between regions. The disparities are described by Rosegrant, Agcaoili-Sombilla and Perez (1995) as a two-tiered system of food security, in which rich and rapidly growing economies enjoy abundant, affordable food supplies, while poor, slow-growing countries suffer from food scarcity and malnutrition. This means that the food security problem is, in the main, not one of shortage but of imbalance and distribution.

Another aspect of food security is sustainability. The concerns are: "can food production continue to keep up with demand in generations to come?" and "is the prosperity of the current generation at the expense of the future?" Some analysts believe that the rapid growth in agricultural production in the last few decades has occurred at great environmental cost (Anderson, 1994). That is, over-exploitation has resulted in natural resources being depleted and the environment being damaged. Indeed, the greater intensity of use of land and water resources and chemicals has created problems such as soil salinization, soil erosion, water pollution, pest resistance, etc. As a result, there are signs of declining rates of growth in yields. For example, it has been shown that the average annual growth rate of paddy rice yield in the world declined from 2.42 percent in 1974-82 to 1.78 percent in 1982-90 (Rosegrant, Agcaoili-Sombilla and Perez, 1995). The corresponding figures were 2.62 and 1.66 percent for Asia and 4 and 1.6 percent for China (Pinstrup-Andersen, 1994). Similar results were found for other crops, including wheat, maize, sorghum and other coarse grains.

Similarly, externalities from agricultural production, and related environmental or "green" issues such as climate change, preservation of wilderness areas and biodiversity, animal welfare and food safety, have received increasing attention in the discussion of agricultural policy in recent years (Alston, Norton and Pardey, 1995).

These concerns suggest that sustainable food security is not only about meeting the increasing and changing demand for food now, but about protecting the environment for future generations. Whether and how this is to be achieved depends on a number of economic, social and political factors, both at the national and international levels. Socio-economic factors with potentially significant effects on future developments in the world food situation include: population and income growth, demographic changes and urbanization on the demand side, as well as technological change and productivity growth on the supply side (Rosegrant, Agcaoili-Sombilla and Perez, 1995). Therefore, future agricultural production and productivity growth depend on, among others, a combination of agricultural, environmental, trade and macro-economic policies at the global level.

Although food security issues are multi-faceted, the discussion here focuses on food availability and production in Asia and the Pacific as a first step towards resolving such issues. Particular attention is paid to the role of investment and agricultural productivity in meeting the challenge of sustainable food security.

Seven member countries in this region were selected for in-depth examination: Australia, the United States, China, India, Indonesia, Japan and South Korea. These countries are chosen because of their importance in the food balance both in the world and the region. For example, China and India are predicted jointly to account for more than 30 percent of the estimated global increase in cereal demand (718 million metric tons) between 1993 and 2020 (Rosegrant and Ringler, 1997). The estimated demand increase from China has raised concerns over China's ability to feed itself and the impact of changes in China's trade position on global food balances and prices (Alexandratos, 1996; Brown, 1995; Fan and Agcaoili-Sombilla, 1997). Indonesia is chosen for similar reasons. Together, these three countries account for nearly 70 percent and 40 percent of the population in Asia and in the world in 1996, respectively (FAO, 1997b).

In addition, Australia and the United States are chosen because of their role as major food exporters to the region. Japan and South Korea, on the other hand, represent (newly) industrialized countries that are major food importers. These differences among the selected countries in the stage of economic development, resource endowments and government policy are central to identifying factors in affecting agricultural productivity growth and the role of government policy.

5.2 Production and productivity growth in agriculture

When evaluating the performance of a production unit or the agricultural sector, it is common to use production (the level of output), productivity (output per unit of input) or efficiency (actual output relative to the potential output or best practices) as indicators. Although these measures are closely related, they can yield different rankings in measuring performance. In general, productivity is the most commonly used measure, be it measured in terms of total factor productivity (TFP) or in partial terms such as labour productivity (output per labour) and yield (output per hectare) for its relative ease in calculation and interpretation.

In the following sections, changes over time in output and productivity growth in different regions are compared and the causes for variations are discussed.

Agricultural development and input use

Agricultural output and productivity vary greatly with the stage of economic development, resource endowments, government policy and agronomic-ecological conditions. However, there is a similar path in agricultural development over time and across countries. Pingali and Heisey (1996) categorized the technological transformation of cereal crop production system into three distinct phases: (i) the land-augmentation phase; (ii) the labour-substitution phase; and (iii) the knowledge- and management-intensity phase. The basic assumption is that the transition from one phase to another is determined by growing factor scarcity, first for land, then for labour and finally for other factors of production, such as machinery and management skills.

The first phase is characterized by area expansion being the main source of output growth, as was seen during the pre-Green Revolution era of the 1950s and 1960s. However, as opportunities for area expansion decline over time, cropping intensity is increased, along with increasing use of water, fertilizers, pesticides and high yielding varieties. This was indeed the case during the Green-Revolution period in the 1970s and early 1980s. Such intensive production results in an increased demand for labour and mechanization, as the production system moves from single-cropping to double- and triple-cropping with increased application of purchased inputs.

Eventually, production reaches the point of diminishing marginal returns to further intensification, as was the case in the late 1980s, the post-Green Revolution phase. Here, better technical knowledge and management skills are used to substitute for traditional inputs. Variety selection, fertilizer timing and placement, water management and pesticide application are some areas in which productivity has improved with reduction in unit cost of production.

The model just outlined is used in the following analysis as the basic framework to explain the changes in input use and in productivity between the 1960s and the 1990s. First, it is applied to various regions in the world, then to the developing and developed countries, and finally to the selected countries in Asia and the Pacific.

Comparisons of agricultural output and input use by regions

Agricultural output along with usage rates for conventional inputs, including land, labour, tractor and fertilizer, in various regions are presented in Table 5.1. It can be seen that in 1994, Asia produced 47 percent of the world's agricultural output and had most of the agricultural (40 percent) and irrigated land (70 percent) and highest total fertilizer use (47 percent). Only in terms of total tractor use does it rank second, following Europe. In terms of input use per hectare, Asia ranks third for both fertilizer and tractors, following Europe and North America.

Notably, output in Asia tripled between 1961 and 1994. This three-fold increase can be attributed to the increase in input use (an 81 percent increase in irrigated land, a 13-fold increase in fertilizer usage, and a 27-fold increase in tractor usage). However, there was only a slight increase (eight percent) in the amount of land used. In terms of factor productivity in Asia, it appears that fertilizer productivity declined by 80 percent from 1961 to 1994 while land productivity increased by 184 percent. Because of the interaction between inputs used, these results should be interpreted with caution. Overall, the information presented in Table 5.1 suggests that although fertilizer usage in Asia is approaching the levels used in Europe and North America, land productivity can be improved further by increasing the degree of mechanization.

Table 5.1 Agricultural output, input use and productivity by regions, 1961 and 1994

Input Use, 1961 and 1994					
	Africa	Asia	Europe	Latin America	North America
1961					
Net ag output (89-91 thousand million US$)	36.68	161.42	123.37	50.79	84.59
Land (million hectares)	155.12	436.21	151.37	102.27	225.71
Irrigated land (million hectares)	7.36	90.17	8.32	8.13	14.35
Percent of land irrigated	4.75	20.67	5.50	7.95	6.36
Tractors (million)	0.26	0.26	5.38	0.46	6.42
Fertilizer (million tonnes)	0.73	3.89	14.29	1.06	14.09
Fertilizer per hectare (kg)	4.68	8.92	94.43	10.33	62.45
Tractor per 1 000 ha (number)	1.65	0.60	35.53	4.53	28.45
1994					
Net ag output (89-91 thousand million US$)	78.81	496.74	186.14	122.42	162.68
Land (million hectares)	190.02	472.56	135.43	156.01	233.28
Irrigated land (million hectares)	12.20	163.17	16.77	17.65	22.11
Percent of land irrigated	6.42	34.53	12.38	11.32	9.48
Tractors (million)	0.59	7.87	12.35	1.67	6.36
Fertilizer (million tonnes)	3.47	61.08	21.98	9.23	32.86
Fertilizer per hectare (kg)	18.26	129.26	162.34	59.17	140.86
Tractor per 1 000 ha (number)	3.12	16.66	91.19	10.73	27.25
Factor Productivity, 1961 and 1994					
	Africa	Asia	Europe	Latin America	North America
1961					
Net output/fertilizer(US$1 000/mt)	50.48	41.47	8.63	48.08	6.00
Net output/HA (US$/ha)	236.49	370.06	815.04	496.66	374.79
1994					
Net output/fertilizer(US$1 000/mt)	22.71	8.13	8.47	13.26	4.95
Net output/HA (US$/ha)	414.72	1,051.18	1,374.48	784.70	697.37

Source: FAO (1997b).

Comparisons of agricultural output and input use, developing versus developed countries

In this section, comparisons were made for trends in land use, production and yield between developing and developed countries and across four commodities (rice, wheat, maize and other grains) for the period 1967-1994. The data were split into two subperiods, which coincided with the peak-green revolution period (1967-1982) and the post-green revolution period (1982-1994). The results are summarized in Table 5.2.

Several points can be drawn from Table 5.2. First, there are substantial variations in growth rates across all commodities, between developing and developed countries, and over time between the two subperiods. Secondly, the growth rates of cereal production and yield show a significant slowdown nearly across the board in the second subperiod. Thirdly, the crop area has been declining, again with only a few exceptions**.** Finally, the growth rates in yield between 1993 and 2020 are projected to be lower than what they were previously, with the exception of "other grains." Those exceptional cases are highlighted with asterisks in Table 5.2.

According to Rosegrant and Ringler (1997), the reduction in land area and production of wheat and other grains in developed countries was primarily policy-induced. It reflects the

Table 5.2 Annual growth rates of crop area, production and yield 1967-1994 (percent)

	Area		Production		Yield		
	1967-1982	1982-1994	1967-1982	1982-1994	1967-1982	1982-1994	1993-2020p
Wheat							
Developed	-0.12	-1.38	1.73	-0.03	1.87	1.35	1.06
Developing	1.45	0.42	5.39	2.94	3.88	2.52	1.30
World	0.48	-0.59	2.88	1.20	2.40	1.80	1.17
Maize							
Developed	0.64	-0.26	3.05	0.69	2.33	1.01	0.84
Developing	0.65	1.36*	3.46	3.66*	2.80	2.27	1.36
World	0.64	0.77*	3.20	1.93	2.52	1.16	1.03
Paddy Rice							
Developed	-0.23	-0.28	-0.14	0.34*	0.09	0.61*	0.53
Developing	0.81	0.21	3.21	2.03	2.38	1.81	1.08
World	0.78	0.20	2.96	1.94	2.17	1.74	1.05
Other Grains							
Developed	0.52	-1.63	1.32	-0.78	0.79	0.85*	0.78
Developing	-0.87	0.12	1.20	0.03	2.08	-0.09	1.24
World	-0.15	-0.79	1.28	-0.52	1.43	0.26	0.85

Source: Rosegrant and Ringler (1997).
p indicates projected, not observed, figures.
* indicates increases in growth rates between 1967-82 and 1982-94.

changes in price support programmes in North America and the Common Agricultural Policy in the European Union, as well as economic and political reforms in the formally centrally planned economies of Eastern Europe and the former Soviet Union. On the other hand, the slowdown of cereal productivity growth in developing countries, particularly in Asia, since the 1980s, was attributed to declining world prices and over-intensification of cereal production. Specifically, declining cereal prices had caused a shift of land out of cereals and into more profitable cropping alternatives, such as horticultural products. Furthermore, the intensity of land use in the late 1960s and 1970s ,when the Green Revolution was in full swing, led to input usage beyond the optimal levels, reducing yield in the later period.

From these observations, it seems apparent that land area available for cropping is unlikely to increase and may fall even further as more agricultural land is diverted to residential and industrial uses. A decrease in cropping area means that a greater burden will be placed on growth in crop yield to meet future cereal demand. Moreover, it appears that over-intensification may have led to resource degradation and hence a slowdown in yield growth. The implication is that, to maintain or increase yield in the future, more emphasis on sustainable agriculture is essential.

The Asian-Pacific countries

The data presented here focus on seven Asian-Pacific countries and, where appropriate, use the United States as a benchmark. Moreover, comparisons are made based on agriculture as a whole rather than by commodity. The countries included are Australia, the United States, China, India, Indonesia, Japan, and South Korea.

Trends in input use, in terms of arable land and labour, and final agricultural output are presented in Table 5.3. The growth rates in labour use are variable. While there tended to be

Table 5.3 Annual average growth rates of labour, land use and agricultural output (percent)

	USA	Japan	Australia	China	Indonesia	India	South Korea
Labour							
1961-1975	-3.27	-3.66	-0.39	3.39	0.51	2.22	0.79
1975-1987	-2.48	-2.53	0.22	0.59	1.60	1.50	-3.40
1987-1994	0.86	-7.29	-1.10	0.98	2.08	2.55	-4.54
Arable Land							
1961-1975	0.23	-1.55	2.43	-0.39	0.00	0.36	0.10
1975-1987	-0.03	-0.53	0.89	-0.38	1.36	0.11	-0.22
1987-1994	0.00	-0.64	0.02	-0.23	-2.98	0.00	-1.17
Final Agricultural Output							
1961-1975	2.26	2.42	3.61	4.09	2.91	2.42	4.65
1975-1987	1.00	0.86	0.93	4.99	4.42	2.58	3.10
1987-1994	2.71	-0.42	1.73	5.15	3.38	4.64	2.29

Source: Rao and Lee (1997); FAO (1997b).

negative or little growth in labour input use in the United States, Japan, Australia and South Korea, there was slight to moderate growth in China, India and Indonesia. In terms of arable land use, the overall picture displayed little to negative growth. In addition, the negative growth was quite substantial in Indonesia and South Korea during 1987-94. The latter result could be attributable to fast industrialization in these two countries.

Agricultural output growth has remained positive from 1961 to 1994 (Table 5.3), with only one exception (Japan). Comparisons of growth rates are more variable, however. For example, during 1975-87, the developed economies (United States, Japan and Australia) experienced a slowdown in production while production in less developed economies (China, India, South Korea and Indonesia) accelerated (Table 5.3).

The slowdown during the period 1975-1987 coincides with the growth deceleration in OECD countries during 1973-1987 in response to the oil shocks and resulting changes in macroeconomic policies (Maddison, 1989). Maddison claims that Asian countries did not suffer as much from the oil price increases because of generally more flexible commodity and labour markets and less institutional rigidity that magnify external price shocks compared to OECD countries. Another reason for strong growth in Asian countries was because of high levels of investment and rising educational levels during that period.

After the recession, during 1987-1994, Japan continued its slide to register a negative output growth (-0.42 percent), the United States showed a strong recovery and Australia recovered but only to half the rate it was before the slowdown. In comparison, China and India had shown strong output growth throughout the observation period. Also, it can be seen from Table 5.3 that, although during 1987-1994 the output growth rate was negative (-0.42 percent) in Japan, labour productivity grew by an impressive 7.41 percent, the highest among the countries listed. The increase in productivity stemmed from the fact that the reduction in output was more than offset by the savings in labour use. In China, output grew at a rate of 4.09 percent per year during 1961-1975 while labour productivity grew only marginally at a rate of 0.68 percent. The differing rates imply that increases in output may have been due to greater use of labour rather than from productivity increases. In contrast, output growth in Japan comes mainly from productivity growth.

Table 5.4 shows the growth rates for partial factor productivity in terms of land and labour. It should be noted that both China and India showed strong growth in output between 1961 and

Table 5.4 Annual average growth rates in labour and land productivity (percent) (1987 Geary-Khamis prices with shadow prices)

	USA	Japan	Australia	China	Indonesia	India	South Korea
Labour Productivity							
1961-1975	5.72	6.32	4.02	0.68	2.39	0.20	3.83
1975-1987	3.57	3.48	0.72	4.37	2.77	1.07	6.74
1987-1994	1.84	7.41	2.87	4.13	1.28	2.04	7.16
Land Productivity							
1961-1975	2.03	4.03	1.16	4.51	2.91	2.05	4.54
1975-1987	1.03	1.40	0.05	5.39	3.02	2.47	3.33
1987-1994	2.71	0.22	1.71	5.39	6.56	4.65	3.51

Source: Rao and Lee (1997); FAO (1997b).

1994 (4.09 to 5.15 percent per annum for China and 2.42 to 4.64 percent for India, Table 5.3) but the results for productivity growth were somewhat different. In particular, China registered a dramatic increase in labour productivity from 0.68 percent per annum in 1961-1975 to 4.37 percent in 1975-1987 and 4.13 percent in 1987-1994; the comparable figures for India were 0.20, 1.07 and 2.04 percent. In general, output growth in both countries was due to the increased use of water and purchased inputs such as high yielding varieties and fertilizers (Wong, 1989).

South Korea and Japan both encountered a slowdown in output growth between 1961-1975 and 1987-1994, but labour productivity grew at impressive rates of 7.41 percent in Japan and 7.16 percent in South Korea during 1987-1994. Despite their high levels of labour productivity, Australia and the United States both encountered a slowdown during the period 1975-1987 in output and labour productivity growth. Although labour productivity picked up again during the period 1987-1994 for Australia, the United States continued its decline.

Growth rates of land productivity, presented in Table 5.4, show that in general less developed countries experienced higher growth than developed countries. Japan from 1961 to 1975 is an exception. This could be the result of land intensification where input-intensive multiple cropping was a common practice to compensate for the scarcity of cultivated land. The national index of multiple cropping in China was 1.31 in 1952, 1.5 in 1978 and 1.58 in 1996 (Lin, 1998). In comparison, the index in India was 1.18 in 1970 and 1.24 in 1980 (Wong, 1989). These figures may explain some of the growth in land productivity in these two countries. Wong (1989) also claims that land reforms in China from collectivization to private ownership had a larger impact on land productivity than in India where land reform changed the land tenure system but not ownership.

Despite strong growth in output and partial factor productivity of labour and land, total factor productivity growth has been found to be negative for China (Tang, 1984; Wen, 1993; Wong, 1989) and India (Wong, 1989). These results indicate clearly that output growth was generated primarily from the expansion of inputs, rather than productivity increases.

Table 5.5 shows the relative labour productivity and yields in the selected Asian-Pacific countries using the 1961 figures for the United States as a benchmark. First, it can be seen that most countries have become more productive over time. Secondly, there are wide disparities among countries with three possible divisions. The first group includes the United States and Australia; the second, Japan and South Korea; and the third, China, Indonesia and India. For example, in 1961, agricultural labour in the United States was two-thirds as productive as that in Australia, nearly 15 to 25 times as productive as that in Japan and South Korea and more than 30 to 40 to times as productive as that in China, Indonesia and India. In 1994, the agricultural

Table 5.5 Indices of agricultural labour and land productivity in selected countries (USA 1961 = 100)

	USA	Japan	Australia	China	Indonesia	India	South Korea
Labour Productivity							
1961	100.0	6.1	149.2	2.3	2.9	3.4	3.6
1975	217.9	14.3	258.9	2.5	4.0	3.5	6.2
1978	252.3	15.1	334.4	2.8	4.3	4.0	8.1
1987	332.1	21.6	282.1	4.2	5.5	3.9	13.5
1994	377.3	35.7	343.8	5.6	6.0	4.5	21.8
Land Productivity							
1961	100.0	415.9	51.9	106.1	106.0	63.6	227.0
1975	132.5	723.5	60.9	196.7	158.3	84.6	422.8
1978	138.1	751.5	74.4	218.4	174.5	93.3	525.6
1987	149.9	855.2	61.3	369.4	226.3	113.3	626.4
1994	180.8	868.4	69.0	533.3	352.8	155.7	797.3

Source: Rao and Lee (1997); FAO (1997b).

labour force in the United States was equally productive as that of Australia, 10 to 20 times as productive as Japanese and Korean agricultural labour and 60 to 80 times as productive as Chinese, Indonesian and Indian agricultural labour. The differences in mechanization and labour quality may explain the differences in the level of and changes in productivity in these countries.

The comparative performance in terms of land productivity (or yield) of arable land shows a different picture (Table 5.5). In this case, Japan and South Korea have the highest yields, followed by China, then by Indonesia, the United States, India and Australia. These results indicate that countries with limited land resources tend to farm their lands more intensively and hence have higher output per unit of arable land. They also reflect differences in climate and water availability.

In summary, it appears that there are substantial variations in input use and productivity among countries and over time. The only trend that is common to the countries examined is perhaps the negative growth in arable land use. Secondly, there are substantial variations in the level of productivity and the rate of productivity growth among developing countries (China, India, and Indonesia), newly industrialized countries (Japan and South Korea) and developed countries (Australia and the United States).

This suggests that there is ample room for productivity improvements in the less developed countries. Meanwhile, the gaps in productivity, as presented in Table 5.5, are closing. Furthermore, the fact that growth in output and various measures of productivity can sometimes move in opposite directions confirms the important distinctions between output growth and productivity growth, and between total and partial factor productivity.

Finally, it is apparent that the slowing or negative growth in global crop area will increasingly place the burden of meeting future cereal demand on productivity improvements. Productivity improvement can come either from using existing inputs more efficiently (moving closer to the production frontier) or from technological change (shifting the production frontier upward), or a combination of both. It has been shown that, with existing technology, efficiency is primarily influenced by human capital, such as farmers' education and experience, access to credit and extension services (Coelli and Battese, 1996). Technological change depends, on the other hand, on investments in agricultural research and extension (Alston, Norton and Pardey, 1995; Antle and Capalbo, 1988; Pray and Evenson, 1991). In the next section, sources of productivity growth are discussed based on a survey of existing literature.

5.3 Factors affecting productivity growth

In explaining productivity growth, economists originally limited themselves to the role of conventional inputs such as land, labour, physical capital, water and chemical inputs. However, the failure to explain productivity growth adequately led them to examine the role of human capital and public goods, such as education, agricultural research and extension and publicly provided infrastructure (Griliches, 1963; Mankiw, Romer and Weil, 1992; Nelson, 1964 and 1981; Solow, 1957). Public policies that have a strong link to agricultural productivity such as policy reforms were also examined (Auraujo, Chambas and Foirry, 1997; Lachaal, 1994; Lin, 1992; McMillan, Whalley and Zhu, 1989; Wiens, 1983).

The rationale for considering research is the belief that investments in research result in increases in the stock of knowledge, which, in turn, either facilitate the use of existing knowledge or generate new technology. Technological advances, whether resulting from changes in input quality or how inputs are combined, lead to productivity gains. Education, training and extension also increase productivity by increasing people's knowledge and skill base, which are essential for technology adoption and efficient use of inputs. Public infrastructure, on the other hand, increases productivity by facilitating the exchange of goods and services.

Technological change

Technological change is recognized by many as one of the most important sources of productivity growth (Antle and Capalbo, 1988). It refers to the changes in the production process that come about from the application of innovation and newly acquired scientific knowledge and technical and management skills. Technological change increases agricultural productivity either by shifting the production frontier upward so that more measured output can be produced with the same amount of inputs or by moving closer to the production frontier so that the same amount of output can be produced with a smaller amount of inputs. Better organizational and management skills not only improve input-output combinations but enable producers to respond more quickly to changing market circumstances (Alston, Norton and Pardey, 1995).

While generation of new technology or knowledge comes from investments in research and development, adoption of technology involves investments by the potential users in both physical and human capital (Antle and Capalbo, 1988). Therefore, adoption of technology depends principally on their applicability and expected returns of the innovation. However, there may be a long lag between development, adoption and productivity gains. Chavas and Cox (1992) found the lag to be up to 15 years between making an investment in research and having an effect on productivity. However, after taking effect, the benefits from an innovation may persist for thirty years or more.

The lag between generation of new technology and its widespread adoption by farmers has important policy implications. First, the adverse effects of reduced public funding to agricultural research and extension on productivity may be under-estimated if the lagged effects are not accounted for. Secondly, the complementarity between research and extension should be taken into account. The former helps the development of new technology, while the latter helps speed up the rate of diffusion and adoption of new technology. Extension can be done more effectively by identifying factors that contribute to technology adoption. As an example, innovators in a farming community can be identified and targeted for extension services.

Since better-educated farmers are found to be more likely to adopt new technology, human capital is a pre-condition for technology adoption and hence productivity growth. Further, if adoption of new technology requires additional investments, lack of access to credit and additional inputs may prevent or slow down technology adoption. Finally, because potential users of new technology often differ in the agronomic-ecological conditions in which they operate, new technology may require adaptive research before it can be transferred successfully to different locations. These impediments to technology adoption mean careful planning and provision of necessary infrastructure are essential to capture the full benefits of new technology.

Agricultural research and extension

Many researchers have explored the roles of research and extension in promoting agricultural growth. Rosegrant and Evenson (1992) found that in South Asia, public research accounted for 30 percent of the output growth, and extension for about 25 percent, with corresponding rates of return being 63 percent and 52 percent, respectively. Pray and Evenson's (1991) survey of Asia found the rates of return to national research investment ranged from 19 to 218 percent, returns to national extension investment from 15 to 215 percent, and returns to international research investment from 68 to 108 percent. Evenson and McKinsey (1991) found that public investment in research accounted for over half of the output growth in India and extension contributed about one-third. The calculated internal rates of return were 218 percent for public research and 177 percent for extension. However, they found that little output growth was attributable to infrastructure. Jamison and Lau (1982) also found that physical capital had little impact on production or profits, as compared to farmer's education and extension services.

Fan (1996) found that public research expenditures accounted for about 20 percent of total production growth in Chinese agriculture during the period 1965 to 1994. The annual rates of return to agricultural research investment in China ranged from 44 percent to 83 percent. Fan (1996) concluded that the rapid growth in agricultural output in China during the 1980s and 1990s was the result of public investments in R&D as well as the institutional and market reforms that began in 1979. He concluded that increases in agricultural research were justifiable; not only did they stimulate additional output growth, but the rate of return to agricultural research was much higher than commercial interest rates.

Despite the high rates of returns from public research investments, agricultural research intensity (ARI), measured as a percentage of Chinese agricultural GDP, was found to have declined from 0.56 percent for the period 1958-1965 to 0.43, 0.44, 0.39 and 0.40 percent,

Table 5.6 Internal rate of return to public and private investments to raise agricultural productivity

	Time period	Country studied	Public R&D (percent)	Private R&D (percent)	Extension (percent)
Makki, Tweeten and Thraen (1996)	1930-1990	USA	27	6	--
Huffman and Evenson (1993)	1950-1982	USA	41	46	--
Chavas and Cox (1992)	1950-1982	USA	28	17	--
Davis (1981)	1964-1974	USA	28-52	--	--
Griliches (1963)	1949-1959	USA	30-50	--	--
Mullen and Cox (1995)	1953-1988	Australia	15-40	--	--
Mullen and Strappazzon (1996)	1953-1994	Australia	18-39	--	--
Thirtle (1996)	1954-1992	UK	15-20	--	--
Maredia and Byerlee (1996)	1965-1990	37 LDCs	5-34	--	--
Rosegrant and Evenson (1992)	Various	S. Asia	63	--	52
Pray and Evenson (1991)	Various	Asia	19-218	--	15-215
Fan (1996)	1975-1994	China	44-83	--	--
Salmon (1991)	1965-1977	Indonesia	151	--	--
Evenson and McKinsey (1991)	1966-1986	India	218	95	--

Source: Adapted from Makki, Tweeten and Thraen (1996).

respectively, for 1966-1976, 1977-1985, 1986-1990 and 1991-1993 (Fan, 1996). Lin (1998) reported that, as part of the overall market reform, the Chinese Government had reduced its fiscal appropriation for agricultural research, shifting funding from institutional supports to competitive grants and cost recovery. As such, it can be expected that an increasing proportion of research activities will move from the public to the private domain.

Other studies on output growth have also shown a high payoff from agricultural research and extension (Table 5.6). The results indicate that the rate of return on research, in most cases, ranged from 15 to 50 percent for both developed and developing countries, but some estimates were as high as 218 percent. The wide disparity among the estimates raises questions regarding the sensitivity of these estimates to the commodity of interest and the use of different time periods and methodologies. Estimates for Asian countries appear to be higher and show a much wider variation than those of studies in the United States. This could be due to the diverse nature of Asian agriculture, which differs from country to country in economic, social and agronomic-ecological conditions. Because of inconsistency in the data and methodology used, it is not possible to make direct comparisons across countries or over time. Nevertheless, the general conclusion that R&D yields relatively high returns seems indisputable.

Human capital

Human capital refers to knowledge, experience and skills possessed by people involved in the production process. It is influenced directly by education, training and extension. Its importance lies in the fact that it has a significant impact on the adoption and the utilization of technology, which in turn, affect the allocation of resources and productivity. A well-trained and well-educated labour force is said to be in a better position to assess changing conditions and make necessary adjustments. This ability is becoming ever more important in an increasingly deregulated and global economy where changes in the commodity markets are frequent and quick responses are required.

The concept of investment in human capital covers not only investments in formal schooling and post-school and on-the-job training, but also investment in the form of improved health and family care. Social capital, on the other hand, refers to one’s ability to utilize social networks and institutions. Social status, education and the range of social institutions available can influence one’s social capital. Social capital is important in that it affects access to physical capital, land title, credit and cooperatives, all of which have implications for resource allocation and, hence, productivity.

Women appear to suffer most severely from having limited access to human and social capital in some developing countries, although a larger proportion of women than men are engaged in agriculture (Quisumbing *et al*., 1995). For example, women account for 70 to 80 percent of household food production in sub-Saharan Africa, 65 percent in Asia, and 45 percent in Latin America and the Caribbean. As such, it has been suggested that empowerment of women and gender equality are important factors for raising productivity and promoting food security in developing countries. Jahnke, Kirschke and Lagemann (1987) also found that low adoption of high yield varieties (HYV) in Africa is attributable to lack of appropriate technology development and few extension services directed to women. These findings suggest that acknowledging the critical role of rural women in Asia and providing them with greater access to resources and human capital are crucial in promoting sustainable agriculture and food security.

Policy reform and prices

The importance of policy reform is increasingly viewed as fundamental for agricultural productivity gains, especially for countries where government intervention in agriculture has been strong. Removing market distortions and allowing market signals to be transmitted to producers is the main objective of structural adjustment programmes by international organizations for economies in transition and countries in debt. Land reform and most land policies, which assign property rights to users so that efficient and responsible use of resources can take place, are other cases where changes in policy can have a significant impact on productivity.

A good example of policy reform is the implementation of China's responsibility system (RS) in the late 1970s, which linked productivity with material rewards. The policy reform was found to have resulted in increased incentives to produce and hence there were increases in crop yields for every major crop (Wiens, 1983). McMillan, Whalley and Zhu (1989) also reported that in response to the RS and price reforms, output in the Chinese agricultural sector increased by over 61 percent and productivity by 32 percent between 1978 and 1984. Moreover, 78 percent of the output growth was attributed to the RS and 22 percent to higher prices for crops. Lin (1992) also found that 47 percent of the growth in agricultural output was attributable to the RS during the same period.

However, Lin (1992) acknowledged that benefits from the RS reform had disappeared by 1984-1987. Similar results were found by Huang, Rosegrant and Rozelle (1996), who indicated that the growth rate of rice production was much higher during the reform period (4.5 percent) than afterwards, during 1984-1992 (1.3 percent). Moreover, while the reform was the most significant source of output growth during the reform period, technology was the most significant source of growth later during 1984-1992. Based on these results, Kalirajan, Obwona and Zhao (1996) concluded that despite the substantial impacts of policy reform on output and productivity growth, they provide only a one-shot boost to agricultural productivity. As such, long-term productivity gains depend more on technical change, investments in agricultural research and human capital and, to a lesser extent, on infrastructure.

By contrast, some government policies have been found to have detrimental effects on productivity. Lachaal (1994) found that direct input subsidies to agriculture reduce productivity growth and were a source of technical inefficiency. In this case, the subsidies encouraged using subsidized materials at the expense of other inputs. It was found that with each 10 percent increase in subsidy, the cost of production increased by 1.8 percent. Similarly, Makki, Tweeten and Thraen (1996) found that government commodity programmes had had little effect on improving agricultural productivity in the United States. They concluded that the interest of United States' agriculture in international competitiveness and low food costs would be better served by focusing on research, extension and education than by commodity programmes. They also cautioned that the debate to reduce public spending on agricultural research and extension should carefully consider the potential long-term implications of such a policy.

International trade

Facilitated by improvements in transportation and communication technology, trade has also been important in diffusing new products and new technologies. It is also clear that opening of economies is strongly associated with rapid economic growth. A case in point is the rapid post-war growth of the most dynamic Asian countries, such as Japan, South Korea and Taiwan, and the low growth of inward-looking economies such as China (before the open-door policy) and India. Statistics have shown that during 1950-1973, the annual average compound growth rate in export volume were relatively high in Japan, South Korea and Taiwan as compared to China, Indonesia and India (Table 5.7). During 1973-1986, export growth declined relative to the previous period in Japan, South Korea, Taiwan and Indonesia, was unchanged in India, and climbed dramatically in China.

However, the opening of an economy does not come without risks, particularly where macro-economic, financial and lending policies are not well in place. The recent Asian financial crises underscore how weak financial policies can undermine much of the gains from trade.

Table 5.7 Average compound growth rate in export volume (percent)

	1950-1973	1973-1986
Japan	15.4	7.6
South Korea	20.3	14.0
Taiwan	16.3	11.6
China	2.7	10.4
Indonesia	6.5	3.3
India	2.5	2.5

Source: Maddison (1989).

Natural resources

Natural resources are critical determinants of food supply. Degradation of natural resources, such as land and water, undermines production capacity and threatens the sustainability of the natural ecosystem (Pinstrup-Andersen and Pandya-Lorch, 1998). Land degradation has been severe in the past few decades. It was found that since 1945, about two thousand million of the world's 8.7 thousand million hectares of agricultural land, permanent pastures, forest and woodland have been degraded through inappropriate agricultural practices, overgrazing and deforestation (Oldeman, 1992).

One major contributing factor to land degradation is the overuse and misuse of irrigation water (Anderson, 1994). Asia contains the majority of the world's irrigated land. Water for irrigation is essentially free, however. Research into various water allocation mechanisms such as attempts to structure economic incentives for water use must be undertaken. To a large extent, these problems can be alleviated by assigning property rights. Poverty reduction as well as government policies to provide access to markets and credit for land improvements and technology would also reduce misuse of water resources. Therefore, agricultural research is a critical input into sustainable agricultural development, particularly as related to land and water management issues.

5.4 The role of investment

Investments in agricultural research and development (R&D) from both the public and private sectors can lead to technology generation and productivity improvements. The impact of investment on agricultural research can be seen most clearly from Rosegrant, Agcaoili-Sombilla, and Perez (1995). In their global food projections to 2020, they assumed a baseline scenario of US$10 thousand million public investment in national agricultural research and extension services. The low-investment scenario, which assumed an annual cut of US$1.5 billion to the current level of public investment, resulted in a fall of 15 percent in crop and livestock yield growth rates by 2020. In contrast, if funding of national and international research were to rise by US$750 million per year, crop yield growth would be six percent higher in 2020 than under the baseline scenario. Although these figures are projections and their accuracy is subject to underlying assumptions, they indicate strongly the negative effects of reduced public investment in research and extension, and the crucial role of investment in increasing agricultural productivity.

Private versus public investments

Table 5.6 indicated that the rate of return is, in most cases, greater from public research than private research (Chavas and Cox, 1992; Evenson and McKinsey, 1991; Huffman and Evenson, 1993; Makki, Tweeten, Thraen, 1996). The higher rate of return from public research is, in part, attributed to economies of scale in the production of new agricultural technology and the spill-over and externalities associated with such research (Schultz, 1964). One example of such externalities is the international flow of germplasm. In this case, research benefits from breeding programmes of one country or research institute are appropriated by users who do not incur the full research costs. Public funding is therefore justified by the public nature of knowledge and the high rates of return to public investments in agricultural research.

Traditionally, most agricultural research is publicly funded. However, in recent years, the costs of agricultural technology generation and transfer are shared increasingly with the private sector, particularly in more advanced countries (FAO, 1996b). The proportion of privately funded research is on the order of 30 to 40 percent of all research expenditures in developed countries (nearly two-thirds in the United States) and about five percent in the less-developed countries (FAO, 1996b). This increase in private research has to do with protection of markets for research results via patents and intellectual property rights (IPR) as well as recent changes in funding policies (Alston, Norton and Pardey, 1995; Lin, 1998).

Private research is attracted to sectors of the market where research results exist and benefits can be privately appropriated (Alston, Norton and Pardey, 1995). This is typically the case in more developed countries where intellectual property rights are well established and protected for inputs such as agrichemicals, agricultural machinery and seeds (FAO, 1996b). Private investments also include on-farm irrigation systems, land improvements, new tractors and combines, livestock breeds and plant varieties, as well as processing, transport and storage facilities for post-production marketing.

Government, therefore, can provide an environment conducive to investment, through guarantee of rights and law as well as policies encouraging investment, as recognized in the World Food Summit Plan of Action items 2 and 3 (FAO, 1996a). In addition, investments in basic infrastructure, human capital, basic research and resource management will still fall more upon the public sector because of the public goods nature of these investments.

5.5 Conclusions and implications

Concerns over food security are driven by the need to feed an increasing population and to protect the environment. One means of addressing these concerns is to increase the food supply locally by improving agricultural productivity. Although productivity varies across commodities and countries according to stage of economic development, government policy and agronomic-ecological conditions, long-term growth in agricultural productivity depends primarily on technological change, improved input use efficiency and conserving the resource base. All of which, in turn, depend crucially upon investments in agricultural research, extension, and human capital.

From the literature survey, some conclusions can be drawn about the driving forces behind agricultural productivity growth in the Asia-Pacific region. Potential growth due to expansion of land under cultivation or increased input use, with the exception of machinery, is limited. This points to technological progress as the key to growth, driven by agricultural research and extension and improvements in human capital. Policy reforms, on the other hand, while extremely important, may provide only a one-shot boost to agricultural productivity, unlike agricultural research and extension from which the contribution to productivity is long lasting.

Agricultural research intensity ratios are found to be relatively low for developing countries in the Asian-Pacific (Table 5.8), as compared to the two percent target suggested by Pardey and Alston (1995) and Pinstrup-Anderson, Lundberg and Garrett (1995). Further, public funding of agricultural research and extension has been reduced both nationally and internationally (Anderson and Purcell, 1996).

Table 5.8 Agricultural research intensity ratios (agricultural research expenditures/value of agricultural production)

Region/Country	Number of countries	1961-1965	1971-1975	1981-1985	Latest Year
Developing Regions	NA	NA	NA	NA	NA
Sub-Saharan Africa, excluding South Africa	17	0.42	0.67	0.76	0.58[a]
South Africa	1	1.39	1.53	2.02	2.59[a]
Asia and the Pacific, excluding China	15	0.14	0.22	0.32	NA
China	1	0.57	0.44	0.42	0.42[b]
Latin America and the Caribbean	26	0.30	0.46	0.58	NA
West Asia and North Africa	13	0.28	0.50	0.52	NA
Developed countries	18	0.96	1.41	2.03	NA
United States	1	1.32	1.36	1.93	2.22[c]
Australia	1	1.54	3.56	4.52	4.42[d]

Source: Pardey and Alston (1995).
[a] 1991 estimate; [b] 1993; [c] 1992; and [d] 1988.

With declining public funding and institutional changes for research, one way to keep up with the growing needs for information and technology is to raise the productivity of public research. Research productivity can be increased with closer collaboration between agricultural research systems by exploiting research synergies and avoiding duplications (Jahnke, Kirschke and Lagemann, 1987). Further, the feedback between scientists and users is essential for generating the right technology and fully capturing the benefits of its utilization (FAO, 1996b). Finally, existing wide disparities in yields among countries in the same region and between continents suggest that considerable improvements in agricultural productivity could be achieved by transferring technology more effectively and efficiently from research centres to potential users and from existing users to new users.

The funding problems facing public research in developing countries also mean that the private sector will play an increasingly important role in applied and adaptive research. This implies that the role of government is to focus investment on basic research, human capital and infrastructure and to provide an environment and incentives, such as property rights, market reforms, more open policies and a stable economy, conducive to private investment.

References

Alexandratos, N. 1996. China's projected cereals deficits in a world context. *Agricultural Economics,* 15: 1-16.

Alston, J.M., Norton, G.W. & Pardey, P.G. 1995. *Science under scarcity: principles and practices for agricultural research evaluation and priority setting.* Ithaca, USA, Cornell University Press.

Anderson, B. 1994. *Sustainable agricultural development and the environment: toward an optimal solution.* Canadian International Development Agency, October.

Anderson, J.R. & Purcell, D.L. 1996. International policies for agricultural research investments. In *Conference proceedings for global agricultural science policy for the twenty-first century*. 16-28 August 1996, Melbourne, Australia.

Antle, J. & Capalbo, S. 1988. An introduction to recent developments in production theory and productivity measurement. In S. Capalbo and J. Antle, eds. *Agricultural productivity measurement and explanation.* Washington, DC, Resources for the Future.

Asenso-Okyere, W.K., Benneh, G. & Tims, W., eds. 1997. *Sustainable food security in West Africa.* Dordrecht, Kluwer Academic Publishers.

Auraujo, B., Chambas, C.G. & Foirry, J.P. 1997. Conséquences de l'ajustement des finances publiques sur l'agriculture marocaine et tunisienne. Unpublished FAO study, March.

Brown, L. 1995. *Who will feed China? Wake-up call for a small planet* New York, USA, W.W. Norton.

Chavas, J.P. & Cox, T. 1992. A nonparametric analysis of the influence of research on agricultural productivity. *American Journal of Agricultural Economics,* 74: 583-591.

Coelli, T. & Battese, G. 1996. Identification of factors which influence the technical efficiency of Indian farmers. *Australian Journal of Agricultural Economics,* 40 (August): 103-128.

Davis, J.A. 1981. Comparison of procedures to estimating returns to research using production function. *Australian Journal of Agricultural Economics,* 25: 60-71.

Evenson, R.E. & McKinsey, Jr., J.W. 1991. Research, extension, infrastructure, and productivity change in Indian agriculture. *In* R.E. Evenson and C.E. Pray, eds. *Research and productivity in Asian agriculture*, p. 158-184. Ithaca, USA, Cornell University Press.

Fan, S. 1996. Research investment, input quality, and the economic returns to Chinese agricultural research. Paper presented to the post-conference workshop on agricultural productivity and R&D policy in China, *Conference proceedings for global agricultural science policy for the twenty-first century*. 16-28 August 1996, Melbourne, Australia.

Fan, S. & Agcaoili-Sombilla, M. 1997. Why projections of China's future food supply and demand differ. *Australian Journal of Agricultural and Resource Economics,* 4:169-190.

FAO. 1996a. *World food summit plan of action*. Rome, FAO.

FAO. 1996b. Investment in agriculture: evolution and prospects. *World food summit technical background documents*, 10. Rome, FAO.

FAO. 1997a. *Sustainable food security: people, institutions, knowledge and environment*. Rome, FAO, Sustainable Development Department.

FAO. 1997b. *AGROSTAT* Database. Rome, FAO, Statistics Division.

Griliches, Z. 1963. The sources of measured productivity growth: United States agriculture 1940-1960. *Journal of Political Economics,* 71: 331-346.

Huang, J., Rosegrant, M. & Rozelle, S. 1996. Public investment, technological change, and reform: a comprehensive accounting of Chinese agricultural growth. Paper presented to the post-conference workshop on agricultural productivity and R&D policy in China, *Conference proceedings for global agricultural science policy for the twenty-first century*. 16-28 August 1996, Melbourne, Australia.

Huffman, W. & Evenson, R.E. 1993. *Science for agriculture: a long-term perspective*. Ames, USA, Iowa State University Press.

Jahnke, H. E., Kirschke, D. & Lagemann, J. 1987. *The impact of agricultural research in tropical Africa: a study of the collabouration between international and national research systems.* CGIAR Study Paper Number 21. Washington, DC, The World Bank.

Jamison, D. & Lau, L. 1982. *Farmer education and farm efficiency*. Washington, DC, World Bank.

Kalirajan, K.P., Obwona, M.B. &. Zhao, S. 1996. A decomposition of total factor productivity growth: the case of Chinese agricultural growth before and after reform. *American Journal of Agricultural Economics,* 78:331-338.

Lachaal, L. 1994. Subsidies, endogenous technical efficiency and the measurement of production growth. *Journal of Agriculture and Applied Economics,* 26 (July): 299-310.

Lin, J.Y. 1992. Rural reforms and agricultural growth in China. *The American Economic Review,* 82 (March):34-51.

Lin, J.Y. 1998. *How did China feed itself in the past? How will China feed itself in the future?* Mexico, DF, CIMMYT Economic Program, Second Distinguished Economist Lecture, January.

Maddison, A. 1989. *The world economy in the 20th century.* Paris, OECD, Development Centre.

Makki, S., Tweeten, L. & Thraen, C. 1996. Returns to agricultural research: are you assessing right? In *Conference proceedings for global agricultural science policy for the twenty-first century*. 16-28 August 1996, Melbourne, Australia.

Mankiw, N.G., Romer, D. & Weil, D.N. 1992. A contribution to the empirics of economic growth. *Quarterly Journal of Economics,* 107 (May): 407-437.

Maredia, M. & Byerlee, D. 1996. Efficiency of wheat improvement research: a comparative analysis of national and international research systems in developing countries. In *Conference proceedings for global agricultural science policy for the twenty-first century*. 16-28 August 1996, Melbourne, Australia.

McMillan, J., Whalley, J. & Zhu, L. 1989. The impact of China's economic reforms on agricultural productivity growth. *Journal of Political Economy,* 97 (August):781-807.

Mullen, J. & Cox, T. 1995. The returns from research in Australian broadacre agriculture. *Australian Journal of Agricultural Economics,* 39:105-28.

Mullen, J. & Strappazzon, L. 1996. The relationship between investment and productivity growth: Australian broadacre agriculture. In *Conference proceedings for global agricultural science policy for the twenty-first century*. 16-28 August 1996, Melbourne, Australia.

Nelson, R. 1964. Aggregate production functions and medium-range growth projections. *American Economic Review*, 54 (September): 575-606.

Nelson, R. 1981. Research on productivity growth and productivity differences: dead ends and new departures. *Journal of Economic Literature,* 19 (September): 1029-1064.

Oldeman, L.R. 1992. Global extent of soil degradation. In *Biannual Report 1991-1992,* p.19-36. Wageningen, Netherlands, International Soil Reference and Information Center.

Pardey, P.G. & Alston, J.M. 1995. *Revamping agricultural R&D*. Washington, DC, International Food Policy Research Institute (IFPRI).

Pingali, P.L. & Heisey, P.W. 1996. Cereal crop productivity in developing countries: past trends and future prospects. In *Conference proceedings for global agricultural science policy for the twenty-first century*. 16-28 August 1996, Melbourne, Australia.

Pinstrup-Andersen, P. 1994. *World food trends and future food security*. Washington, DC, International Food Policy Research Institute.

Pinstrup-Andersen, P., Lundberg, M. & Garrett, L. 1995. *Foreign assistance to agriculture: a win-win proposition.* Washington, DC, International Food Policy Research Institute.

Pinstrup-Andersen, P. & Pandya-Lorch, R. 1998. Food security and sustainable use of natural resources: a 2020 vision. *Ecological Economics*.

Pray, C.E. & Evenson, R.E. 1991. Research effectiveness and the support base for national and international agricultural research and extension programs. In R.E. Evenson and C.E. Pray, eds. *Research and Productivity in Asian Agriculture*. Ithaca, USA Cornell University Press.

Quisumbing, A.R., Brown, L.R., Feldstein, H.S. Haddad, L. & Peña, C. 1995. Women: the key to food security. Washington, DC, International Food Policy Research Institute.

Rao, D.S.P. & Lee, B. 1997 Agricultural sector performance in selected Asian-Pacific countries 1961-1994. Paper presented to the seminar on Asian economies in the twentieth century: an Australian perspective, Brisbane, 27-28 November 1997.

Rosegrant, M.W., Agcaoili-Sombilla, M. & Perez, N.D. 1995. *Global food projections to 2020: implications for investment.* Washington, DC, International Food Policy Research Institute.

Rosegrant, M.W. & Evenson, R.E. 1992. Agricultural productivity and sources of growth in South Asia. *American Journal of Agricultural Economics,* 74 (August): 757-761.

Rosegrant, M.W. & Ringler, C. 1997. World food market into the 21st century: environmental and resource constraints and policies. *The Australian Journal of Agricultural and Resource Economics,* 41 (September): 401-428.

Salmon, D.C. 1991. Rice productivity and the returns to rice research in Indonesia. In R.E. Evenson and C.E. Pray, eds. *Research and Productivity in Asian Agriculture*, p. 133-157. Ithaca, USA, Cornell University Press.

Schultz, T.W. 1964. *The economic value of education.* New York, Columbia University Press.

Solow, R. 1957. Technical change and the aggregate production function. *Review of Economics and Statistics,* 39 (August): 312-320.

Tang, A. 1984. An analytical and empirical investigation of agriculture in mainland China, 1952-80. Taipei, Taiwan, Chung-Hwa Institute for Economic Research.

Thirtle, C. 1996. Productivity and returns to levy-funded R&D in UK sugar: an alternative approach to rate of return calculations. In *Conference proceedings for global agricultural science policy for the twenty-first century*. 16-28 August 1996, Melbourne, Australia.

Wen, G.J. 1993. Total factor productivity change in China's farm sector: 1952-1989. *Economic Development and Cultural Change,* 42:1-41.

Wiens, T.B. 1983. Price adjustment, the responsibility system, and agricultural productivity. *American Economic Review,* 73 (May):319-324.

Wong, L. 1989. Agricultural productivity in China and India: a comparative analysis. *Canadian Journal of Agricultural Economics,* 37: 77-93.

6. Agricultural production in Peru (1950-1995): sources of growth

Jackeline Velazco

This study examines trends in growth in agricultural production in Peru for the period 1950-1995, identifying factors that affect agricultural growth and pinpointing where the constraints lie. Regional differences are examined along with production and supply. Econometric models are estimated for an aggregate agricultural production function and supply functions for three representative commodities. The overall findings indicate that public investment along with favourable expected prices and weather conditions are prerequisites for private investment, and hence growth in agricultural output.

6.1 Introduction

A key feature of Peru's agricultural sector is that it accounts for a high proportion of the national workforce. The 1993 census shows the EAP (Economically Active Population) in agriculture represent 26.7 percent of the national EAP (Instituto Nacional de Estadística e Informática (INEI), 1995). On the other hand, agricultural production only accounts for some 13 percent of total GDP, with a downward trend since 1950. Hence the need to raise the yield of production factors, given that the sector is faced with the dual challenge of increasing national food supply and providing growth opportunities for agribusiness and exports.

The objective of this paper is to identify trends in agricultural growth in Peru and identify and quantify the factors enhancing or inhibiting agricultural growth. Special attention will be paid to regional differences within Peru. Section 6.2 focuses on production trends of major crops in Peru and trends in the factors affecting them. These factors are discussed in subsections and include, use of conventional inputs (land, labour and fertilizer), investments, technological change, agricultural policies, political violence and external debt. Subsections on investments address both public investments in infrastructure and private investment in machinery. Subsections on technological change look at the supply of technical information and investment in human capital that permits utilization and creates demand for technical information.

Section 6.3 examines regional differences in agriculture in response to the imposition of a structural adjustment program in Peru in 1990. The purpose of the subsections within 6.3 is to identify the characteristics of the farmers in greatest difficulty (and their coping strategies) as well as those of the farmers with relative success.

In section 6.4 models of the factors affecting agricultural production and supply are estimated using national data. The objective is to determine the relative importance of different factors on agricultural output in Peru by quantifying their contribution. This permits assessing the relative importance of various inputs, policy, investment, climate and political violence on Peru's agricultural sector. Conclusions from these sections are discussed in section 6.5

6.2 Sources of growth in agriculture

This section begins by examining the historical and regional trends in Peruvian agriculture. Subsequent parts of this section examine the major factors affecting agricultural production in Peru: land, labour and fertilizer, investments, technological change, agricultural policies, political

Table 6.1 Production growth in terms of increased area and yield: 1950-1995

COMMODITY	Annual Growth in Production	Disaggregated Rates			
	(percent)	Area		Yield	
		Growth rate	(percent)	Growth rate	(percent)
POTATO					
National	**0.41**	**-0.95**	**0.00**	**1.36**	**100.00**
Ancash	-1.95	-1.65	84.62	-0.30	15.38
Cajamarca	2.05	0.52	25.37	1.53	74.63
Cusco	-0.56	-1.52	0.00	0.96	100.00
Huanuco	3.13	1.68	53.67	1.45	46.33
Junin	0.46	-1.38	0.00	1.84	100.00
La Libertad	1.60	0.33	20.63	1.27	79.38
Lima	0.62	-1.50	0.00	2.12	100.00
Puno	-0.17	-2.12	0.00	1.95	100.00
COTTON					
National	**-2.66**	**-3.30**	**0.00**	**0.64**	**100.00**
Ancash	-1.33	-2.98	0.00	1.65	100.00
Arequipa	-5.10	-6.35	0.00	0.42	100.00
Ica	-1.81	-2.23	0.00	0.42	100.00
Piura	-1.22	-1.55	0.00	0.33	100.00
Lima	-2.75	-5.25	0.00	2.50	100.00
YELLOW FLINT MAIZE					
National	**1.34**	**0.82**	**66.67**	**0.52**	**33.33**
Lambayeque	4.94	0.62	12.55	4.32	87.45
La Libertad	2.83	0.98	34.63	1.85	65.37
Ancash	0.39	-0.53	0.00	0.92	100.00
Lima	0.01	-0.82	0.00	0.83	100.00
San Martin	10.86	5.30	48.80	5.56	51.20
Piura	5.62	3.26	58.01	2.36	41.99
SOFT MAIZE					
National	**1.32**	**0.52**	**39.33**	**0.80**	**60.67**
Ancash	-0.45	0.35	100.00	-0.80	0.00
Apurimac	2.65	-0.15	0.00	2.80	100.00
Cajamarca	4.44	0.77	17.23	3.68	82.77
Cusco	-0.38	0.32	100.00	-0.70	0.00
Junin	0.27	-0.33	0.00	0.60	100.00
Piura	4.39	0.99	22.46	3.40	77.54
RICE					
National	**5.24**	**3.12**	**59.54**	**2.12**	**40.46**
Arequipa	6.61	4.25	64.30	2.36	35.70
Cajamarca	2.88	2.45	85.07	0.43	14.93
La Libertad	0.70	0.22	31.43	0.48	68.57
Lambayeque	2.04	0.62	30.39	1.42	69.61
Piura	4.74	3.88	81.86	0.86	18.14
ASPARAGUS*					
National	**1.26**	**0.01**	**0.63**	**1.26**	**99.37**
Ica	9.05	3.06	33.85	5.99	66.15
La Libertad	11.30	-0.64	0.00	11.93	100.00

Source: MAG, 1992 and 1994; MAG *Estadistica Agraria Mensual*, selected years.
* The data for asparagus date from 1966.
Note: By definition Q = A*Y, where: Q = Total production; A = Harvested area; Y = Yield. The sum of the growth rates A and Y equals the growth rate for Q. The following equations were estimated to determine the growth rates for A and Y: LnA = a + b (time) + Dummy and LnY = c + d (time) + Dummy. Thus, Q = b + d. The dummy variable covers the effects of climate in the years 1957-1958, 1991-1992 and 1993. The regressions were corrected for autocorrelation problems.

violence and external debt. Table 6.1 gives a breakdown of Peru's agricultural production growth in terms of area and yield at the national and regional level for the period from 1950 to 1995. The regional units of analysis are relevant agricultural departments (government administrative units). Selected commodities include exportable goods such as cotton and asparagus, imported items such as rice and yellow flint maize and non-tradables such as potato and soft maize, which are both mainly produced on smallholdings in the Andean highlands.

From Table 6.1 it is evident that national potato production increased exclusively due to improvements in yield. For cotton, output decreased at the annual rate of 2.7 percent driven by reductions in the area sown, despite gains in yield. For yellow flint maize, production increases are due primarily to increases in area, but yield increases are also strong. A similar pattern is found for rice. Increases in soft maize production are largely due to increases in yield, but also to hectares sown. Growth in asparagus production was overwhelmingly due to increased yield.

These results are at the national level, but it is also important to look at regional differences shown by the departmental data. The regional yield situation for 1950-1995 shows varied performance, with no quantum leaps in production to indicate widespread technological innovation.

Trends in the use of land, labour and fertilizer

The vast majority of farmers have medium and smallholdings but control a small portion of cultivated land in Peru. The agrarian reform of 1969 abolished large estates (*latifundio*) and the subsequent restructuring of the coastal cooperatives and Sociedades Agrícolas de Interés Social (SAIS) in the sierra in the 1980s produced a tenure structure which has increased the area held by small producers. Table 6.2 indicates that in 1972, two percent of farmers had holdings of more than fifty hectares but controlled 79 percent of the total area. By 1994 three percent of farmers had access to 77 percent of the land area. Agricultural censuses for 1972 and 1994 show an increase in agricultural land area of 51 percent.

In a recent study, Zegarra (1999) used data from the 1961, 1972 and 1994 agricultural censuses to examine changes in the concentration of land. Using non-standardized land data in

Table 6.2 Agrarian structure in Peru: 1972 and1994

Census	1972		1994	
	N°	percent	N°	percent
Total Farmers	1 390 238	100	1 745 773	100
Total area	23 545 056	100	35 637 808	100
Less than 0.5 ha				
Farmers	336 695	24	213 069	12.2
Area	83 203	0.3	306 795	0.86
0.5 to 4.9 ha				
Farmers	747 030	54	1 015 273	58.2
Area	1 477 155	6.3	2 021 200	5.7
5 to 9.9 ha				
Farmers	153 141	11	246 183	14.1
Area	1 010 495	4.3	1 631 771	4.6
10 to 19.9 ha				
Farmers	78 699	5.6	135.684	7.8
Area	1 025 926	4.4	1 778 581	5
20 to 49.9 ha				
Farmers	46 648	3.4	83 916	4.8
Area	1 339 423	5.7	2 434 809	6.8
50 and more ha				
Farmers	28 025	2	51 648	2.9
Area	18 608 855	79	27 464 653	77.04

Source: Second National Agricultural Census of 4 to 19 September 1972.
Final national results, page 2. INEI.
Third National Agricultural Census, 1994. Page 46.
Compiled by the author.

hectares, he calculated a Gini coefficient of 0.94 in 1961. A small reduction in concentration to 0.88 in 1972 was the result of the first phase of agrarian land reform. By 1994, the coefficient reached 0.51, the result of the land redistribution process. Standardizing the data according to access to irrigation, the Gini coefficients are 0.57 in 1972 and 0.25 in 1994. The values indicate a pattern of improving equality in the distribution of land.

The smallest holdings (*minifundio*) predominate in the coastal, highland (*sierra*) and tropical rainforest (*selva*) regions. The situation is compounded by the fact that parcels of land tend to be subdivided because of population pressure, restricting the possibility of generating sufficient income to maintain a rural household and making it difficult to innovate or adopt technology. Amat and Leon (1996) offer the following conclusion regarding land availability:

> "The cultivated area equals approximately 49 percent of potential cropland of 7.6 million hectares. The arable land reserve of 4.4 million hectares is located mainly in the *selva* and coastal areas (18 and 82 percent, respectively). The situation in the highlands is radically different, as land is overcropped and overgrazed, i.e. unsuitable land is cultivated and even protected areas are grazed. Overuse is estimated at 500 000 hectares in the case of cropping and 2.6 million hectares in that of grazing" (Amat and Leon, 1996: 45-46).

Regarding changes in employment, the average annual rate of growth of the agricultural economically active people (EAP) was 0.81 percent for 1970-1995 (INEI, selected years). However, the agricultural EAP as a proportion of national EAP dropped from 59 percent in 1950 to 26.7 percent in 1993. The 1993 census indicates an increasing importance of trade and service activities (Instituto Cuanto,1994).

Fertilizer consumption (nitrogen and phosphorus) for 1945-1969 rose by an average 11 percent per year until the mid-1950s, then fell, rose and fell again in the late 1960s. Hopkins (1981) attributes these trends to the fall in the supply of island guano from the mid-1950s when demand had to be met through fertilizer imports. This meant the supply of fertilizer depended on the availability of hard currency, international prices and exchange rates. High production costs of the newly established local fertilizer industry coupled with import tariffs, caused price increases. Another important aspect is the increase in fertilizer use according to the size and location of land holdings. The 1972 Agricultural Census revealed regional differences in this regard:

> "In 1972, only one of every six holdings in the sierra used chemical fertilizer and/or island guano; the situation in the *selva* was even worse (one in sixteen). The coastal area continued to be the main user of this type of fertilizer, accounting for over 84 percent of nitrogen, phosphorus and potassium consumption." (Villagarcía 1974; cited by Figueroa 1975:127). (Hopkins 1981:105).

The average annual rates of growth of fertilizer consumption have been estimated for 1970-1995 with a semi-logarithmic function and the FAO database. Although there is an aggregation problem when totalling the consumption of a variety of fertilizers, the results do portray a cyclical consumption pattern. An expansion phase from 1970 to 1980, with an annual consumption increase of 3.7 percent. This is followed by a decline of 11 percent between 1980 and 1985, an annual increase of 35 percent from 1985 to 1988, a drop of 33 percent from 1988 to 1991 and, finally, an annual expansion of 26 percent from 1991 to 1994. From 1980 to 1989, the coast accounted for 73.1 percent of sales, followed by the highlands with 24.2 percent and the rainforest with 2.7 percent (Velazco, Velazco and Sulen, 1990). Given the demand for fertilizer is highest on the coast where cash crops dominate, the fall in real prices of agricultural goods and availability of foreign exchange are probably the reasons for this particular pattern of fertilizer consumption.

Figures for 1994 indicate that 74.6 percent of coastal holdings applied chemical fertilizer (accounting for 82.3 percent of the region's agricultural land area) and that fertilizer use rose in proportion to size of holding. It should be noted, however, that fertilizer use on the coast is generally quite high on holdings of less than three hectares (74 percent) when compared to holdings of 50 hectares or more (90.8 percent). This contrasts with the highlands where only 39.6 percent of holdings use chemical fertilizer (covering 40.7 percent of the region's area). In terms of size, 41.1 percent of the area in holdings of under three hectares use chemical fertilizer against 41.3 percent of the area in holdings of 50 hectares or more. Clearly fertilizer use is low in the highlands. It is even lower in the rainforest where 11.3 percent of holdings, covering 14.7 percent of the area, use chemical fertilizer,. Farms under three hectares use fertilizer on only 11.5 percent of their area, while farms of 50 hectares or more use fertilizer on 16.2 percent of their area (Third National Agricultural Census, 1996).

Investment in agriculture

This section compares the changes in macro-economic indicators, such as rate of total GDP growth and level of inflation, with components of agricultural investment. It begins by outlining economic performance for 1950 to 1995. From 1950 to 1975 the economy experienced growth (2.57 percent per year). This was followed by a recessionary phase from 1976 to the early 1990s during which GDP fell by 1.59 percent per year (Gonzales, 1996). GDP climbed from 1992 to 1996. Availability of information on the composition of agricultural investment restricts the analysis to 1970 to 1995, more precisely to the expansionary phases of 1970 to 1975 and 1993 to 1995 and to the recessionary phase of 1976 to 1992. A number of conclusions can be drawn from Table 6.3.

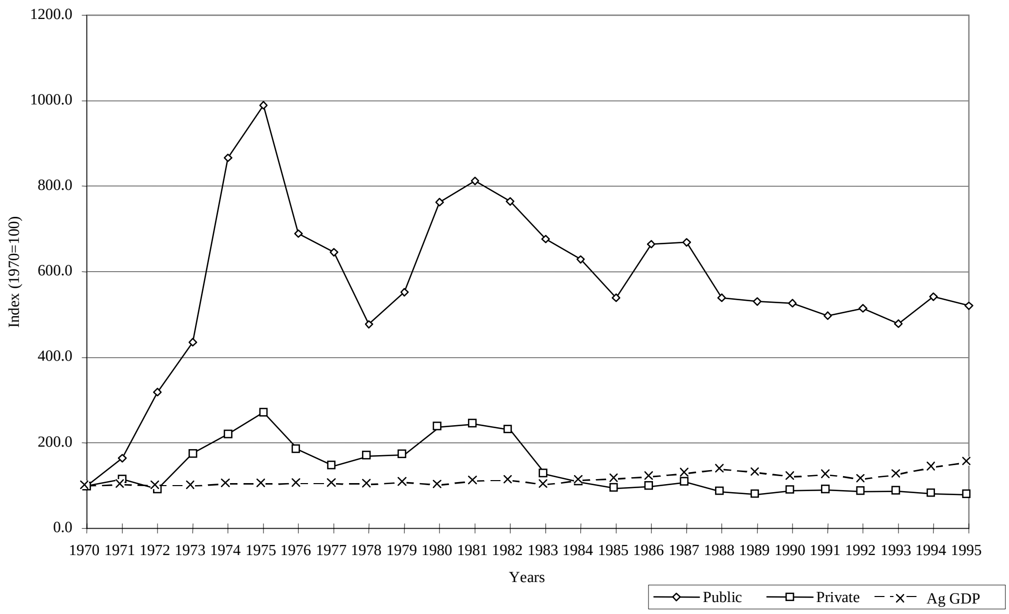
The economy as a whole grew faster during 1970 to 1975 than the agricultural sector. The onset of Peru's agricultural crisis can be dated from the 1970s when the rate of production growth was lower than the rate of population growth (Hopkins, 1981). The resulting deficit was covered by higher food imports. However, agriculture grew faster than the economy from 1976 to 1995.

Table 6.3 Total GDP, agricultural GDP, inflation and investment in agriculture for Peru (average annual rates of growth)

Variable	**1970-75**	**1976-92**	**1993-95**	**1970-95**
GDP	5.02	0.27	8.76	2.24
GDP Agriculture	0.73	0.83	9.20	1.82
Inflation	13.78	785.00	21.70	534.00
Agricultural Investment	29.50	(4.30)	(1.60)	2.80
Ag. Public Investment	61.60	(2.40)	0.80	10.80
Ag. Private Investmemt	27.00	(4.60)	(3.00)	1.90
Machinery & equipment	25.90	1.20	(2.50)	5.70
Land Improvements	73.00	(3.00)	(2.00)	12.30
Livestock & Plantations	28.00	(4.30)	(0.70)	2.60

Note: The bracketed values are negative growth rates
All variables are expressed in soles at constant 1979 value.
Source: "Peru: Compendio Estadístico". 1990-92, 1995-96. Lima: INEI, "Los Ciclos Económicos en el Perú: 1950-1995". Lima: INEI, March 1996. Compiled by the author.

FIGURE 6.1
Evolution of public and private investment and agricultural GDP in Peru



Public investment in agriculture during the general economic expansion phase increased at an annual rate of 61.6 percent during 1970 to 1975, while private investment rose at 27 percent annually, its highest level during the period under study. Figure 6.1 clearly shows the changing pattern of public and private investment and agricultural GDP. Analysis of the components of agricultural investment with the highest growth spotlights land improvements, which rose by 73 percent per year.

The recessionary phase from 1976 to 1992 was accompanied by high levels of inflation and reductions in agricultural investment. Public and private investment fell simultaneously, the former by an annual –2.4 percent and the latter by –4.6 percent. In the post-adjustment period (1993 to 1995) of revitalized domestic and agricultural growth, public investment recovered slowly (0.8 percent) while private investment remained negative.

The trends in public and private investment (Figure 6.1) suggest that the performance of private and public investment moved very much in parallel throughout the period 1970 to 1995. The Granger causality test[1] supports the hypothesis that public investment explains the

[1] The results of the Granger causality test between the log of public investment (LnPub) and the log of private investment (LnPri) are:

Null Hypothesis	F-Statistic	Probability
LnPri does not Granger cause LnPub	2.55	0.0943
LnPub does not Granger cause LnPri	15.38	7.6E-05

These results refute the suggestion that public investment does not Granger cause private investment, in other words they support the existence of causality from public investment to private investment. In addition, the correlation coefficient between investments for 1970 to 1994 is 0.67, a 95 percent significance level.

behaviour of private investment suggesting that private agricultural investment grows in response to a prior increase in public agricultural investment. Thus, there would appear to be a complementary relationship between public and private investment for the agricultural sector for the period 1970 to 1995. If this is the case, the recovery of public investment during the post-adjustment period should stimulate private investment in the coming years.

This contrasts with the findings of Gonzalez (1996) for the economy as a whole and the supposed relationship between public and private investment for 1950 to 1995. The author finds that at times public and private investment are complementary, but that there was crowding-out during the recessionary phase (1976-1993) driven by the impact of the external debt on savings and public investment.

Regarding the relative proportions of agricultural investment, private investment for 1970 to 1992 was greater, accounting for 75 percent of the total against 25 percent from public investment (INEI, selected years). The private sector accounted for 70 percent of the purchase of machinery and equipment during 1970 to 1979, but public investment increased its share to over 50 percent in the following period. Investment in land improvement, on the other hand, was overwhelmingly government-initiated (94 percent). In contrast, private investment in permanent plantations and livestock was 98 percent of the total. These figures suggest a degree of specialization of agricultural investment which has remained relatively unchanged since 1970 (INEI, selected years).

Comparison of investments in terms of domestically produced or imported items indicates that imports (including transportation equipment, machinery, agricultural and industrial equipment and other capital goods) accounted for 31 percent of the total for 1970 to 1983 but only 15 percent for 1984 to 1995 (INEI, selected years).

Public investment in agricultural infrastructure

Various authors have investigated the importance of public investment in infrastructure on agricultural production. Dutt (1991) uses a two-sector model (agriculture and industry) to demonstrate that "agricultural growth is constrained by agricultural infrastructure, which in turn is constrained by public expenditure. Given that the main source of tax revenue for governments in less developed economies is the industrial sector, faster industrial growth – due to a more equal distribution in industry or agriculture – will increase government tax revenues, increase public investment in agricultural infrastructures and remove the agrarian barrier" (Op cit.:344). With regard to agriculture in India, Kenya and Sudan, Von Oppen, Njehia and Tifijaimi (1997) show that improvement in market access and sites for producers has a positive impact on the efficient allocation of resources on small, medium and large holdings, thereby increasing overall productivity. Barro (1990) proposes a model that ties growth to fiscal variables.

Public investment in Peru has targeted the agricultural sector since the beginning of the century. This is because the mainstay of economic growth was export-based agriculture in the coastal region. The primary concern was to make sure that this region received sufficient water, thus removing a constraint to expanding the area under cultivation. Thus, public investment in irrigation in 1905 accounted for 8.7 percent of the total, reaching 18.62 percent in 1912, a trend that continued in the 1920s. This investment was financed by fiscal revenue from a progressive income tax and taxation on mineral export earnings. Another important source was the policy of external debt (Portocarrero, Beltrán and Zimmerman, 1988).

In general, the largest share of public investment in agriculture was directed towards irrigation in the coastal region. Between 1950 and 1980, 90 percent of irrigation investment was directed to the coastal region, the rest to the highlands. Some 76 percent of investment in the coastal

Table 6.4 Allocation of public investment in agriculture

Year	Technology transfer and agricultural development (percent)	Agro-industry and marketing (percent)	Expansion of cultivated area (percent)	Forestry/ wildlife (percent)	Public investment (million 1979 soles)
1971	9.6	1.6	78.2	2.2	4.8
1972	18.0	4.2	70.4	0.2	7.9
1973	8.6	2.2	76.4	1.9	15.3
1974	13.9	4.4	77.5	1.6	20.9
1975	3.9	0.3	93.9	0.9	41.6
1976	5.7	3.1	87.6	1.5	47.5
1977	4.5	3.0	90.6	1.1	33.1
1978	7.7	4.3	85.7	1.4	31.0
1979	8.1	2.9	86.6	1.5	22.9
1980	2.9	7.7	73.6	2.1	26.5
1981	3.8	1.3	80.8	1.2	36.6
1982	6.2	7.6	62.1	1.3	39.0
1983	5.9	2.8	68.5	0.5	36.7
1984	5.0	3.9	62.8	0.8	32.5
1985	5.9	6.1	42.5	0.5	30.2
1986	10.2	6.7	58.1	0.8	25.9
1987	6.8	7.5	67.0	0.5	31.9
1988	1.4	3.6	74.4	0.3	32.1
1989	0.6	1.3	90.0	0.2	25.9
1990	2.6	3.6	85.4	0.3	25.5
1991	3.6	5.8	80.3	0.5	25.3
1992	6.9	8.2	71.2	0.8	23.9
1993	6.1	3.1	75.1	1.1	24.7
1994	5.7	0.5	76.7	1.2	23.2
1995	6.8	0.2	74.3	1.0	26.0
1996	9.2	0.3	56.9	2.3	25.0

Sources: 1971-1987: IICA, 1990, page 53.
1988-1989: Values for these years have been estimated on the basis of a linear trend.
1992-1996: MAG. Reports of the Office of Agricultural Investment, Ministry of Agriculture, mimeo.

region between 1978 and 1982 was concentrated in three major irrigation projects at Majes, Chira-Piura and Tinajones (Guerra, 1986). This trend was maintained in the 1990s.
Insert table 6.4 about here

Public agricultural investment has been a key policy instrument employed to promote the expansion of area under cultivation, to establish and maintain agricultural infrastructure and to pursue programs of technology transfer and agricultural development (Table 6.4). Analysis of the allocation of public investment from 1971 to 1995 indicates that on average 75.8 percent of funds were used to expand area under cultivation and that investment in technology transfer and agricultural development was limited and piecemeal (IICA, 1990; and MAG, 1992).

When examining central government expenditure in agriculture as a percentage of GDP, Gonzales (1996) observed a proportional decline in 1980-1991, before structural adjustment. Gonzales notes that government investment in the rural sector fell by two-thirds over this period, compromising its ability to carry out basic functions. A similar trend was noted for social expenditure and current expenditure on infrastructure, energy, transport and communications, housing and construction and multi-sector programmes.

Priority in road infrastructure has been given to repair, with 1 101 kilometres repaved as of May 1994. This reflects the stronger focus on transport and communications by the central government, rising from 11 percent of infrastructure investment in 1991 to 29 percent for 1992-1995 (Webb and Fernandez Baca, 1996). Such investment is important as "it enables agricultural inputs and production to be mobilized more cheaply and in less time, bringing new regions and populations into the market network and creating conditions for greater investment in the agricultural sector" (Vásquez, 1995:85).

The present government continues to invest in large public works in the coastal region, although more recent infrastructure investment focuses on smaller farmers. The budget report for 1992 to 1995 indicates a beneficiary population of over 130 000 households and shows that 54 percent of expenditure was for construction or renewal of small irrigation channels (Alfaro, Monge and Figueroa, 1997).

Capital investment in tractors and agricultural machinery

Alvarez (1974), Maletta and Foronda (1980) and Hopkins (1981) review the status of investment in tractors and agricultural machinery in Peru since the 1940s. In 1961, the distribution of tractors by region was: 80 percent in the coastal region, 17 percent in the highlands and three percent in the rainforest (Alvarez, 1974). These proportions were much the same in 1972, when 73 percent of tractors were in the coastal departments of Ica, Piura, Lima and Callao, Lambayeque and La Libertad. National tractor distribution by crop was: 35 percent for cotton production, nine percent for sugar cane, seven percent for rice and 17 percent for cereals (Alvarez, 1974). This corresponds to coastal agriculture production patterns. Hopkins' concludes from this:

> "In 1972, mechanization and semi-mechanization continued to be very limited, only existing on any significant scale in the coastal region. In the highlands, some 97 percent of agricultural households function exclusively with animal and human energy and the percentage is even higher in the rainforest. There are four basic reasons for this: 1) the physical environment of agricultural activities; 2) the small size of holdings and their extreme fragmentation; 3) the availability of relatively cheap labor which is more 'competitive' in comparison to the high cost of purchasing, maintaining and repairing machinery; and 4) the range of technology options offered by foreign manufacturing companies are not particularly suited to the requirements of Peruvian agriculture, particularly that of the highlands and the rainforest." (Hopkins 1981:111).

The 1994 Agricultural Census corroborates the sparse distribution of machinery ownership. It reveals that, nationally, 0.8 percent of holdings, accounting for 2.5 percent of cultivated area, had cultivators. Further, 0.6 percent had a wheeled tractor accounting for 5.6 percent of cultivated area; one percent had an engine-driven sprayer accounting for 4.5 percent of cultivated area; and 1.6 percent had a vehicle for transportation accounting for 7.2 percent of cultivated area. The 1994 Census also provides information on ownership of traditional farm implements. It showed that 41 percent of farmers did not have ploughs, four percent had an animal-powered iron plough, 32 percent had an animal-powered wood plough and 22 percent had a human-powered wood plough (a *chaquitaclla*). Respectively, these represent 68, three, 12 and ten percent of cultivated area. A mere 17 percent of farmers had a manual crop sprayer, accounting for 18 percent of cultivated area. Table 6.5 compares farmer technical profiles in the two census years of 1972 and 1994. The conclusion is that in spite of the increase in use of fuel-based energy (from 2.1 to 4.3 percent of holdings), electrical power (from 0.2 to 0.6 percent), ploughs (from 46.6 to 58.9 percent) and tractors (from 5.4 to 15.9 percent), most farmers still use traditional farm implements.

Technological change

With regard to innovation of selected commodities, considerable progress has been made in the research and generation of improved varieties. The Agricultural University of La Molina (UNALM), the National Institute of Agricultural Research (INIA) and the International Potato

Table 6.5 Technical profile of agricultural holdings in Peru

TECHNICAL CHARACTERISTICS	YEAR: 1972		YEAR: 1994	
	number	percent	number	Percent
Total Agricultural Holdings	1 390 877	100.00	1 755 180	100.00
1. Sources of energy				
a) Only human	387 368	27.85	542 817	30.93
b) Only animal	631 646	45.41	926 755	52.80
c) Only engine	29 653	2.13	76 009	4.33
d) Engine and animal	55 969	4.02	199 803	11.38
2. Use of electrical energy	2 609	0.19	9 796	0.56
3. Use of tractors	75 278	5.41	279 667	15.93
a) Ownership of tractors	5 265	0.38	9 406	0.54
b) Hiring of tractors	1 095 674**	78.76	-	-
c) No tractor use	1 018 201	73.21	1 475 513*	84.07
4. Use of ploughs	648 323	46.61	1 032 891	58.85
a) Owned	654 995	47.09	-	-
b) Rented	447 696**	32.19	-	-
c) Not used	456 499	32.82	725 603*	41.34
5. Use of seeds				
a) Bought	264 956	19.05	-	-
b) Improved seeds and/or seedlings	-	-	291 407	16.60
6. Use of fertilizer and/or island guano	210 495	15.13	-	-
a) Chemical fertilizer	-	-	662 678	37.76
b) Bio-manure	-	-	959 573	54.67
7. Use of pesticides				
a) Insecticides	-	-	706 742	40.27
b) Herbicides	-	-	182 262	10.38
c) Fungicides	-	-	400 821	22.84
8. Use of credit	74 935	5.39	269 287	15.34
9. Technical assistance	47 465	3.41	163 739	9.33
10. Irrigation system				
a) Only river	245 114	17.62	416 164	23.71
b) Groundwater/well	12 739	0.92	18 584	1.06
c) Other sources	146 591	10.54	292 893	16.69
11. Irrigated holdings	419 862	30.19	792 543	45.15

Source: INEI – Second National Agricultural Census 1972 (Tables 28,29,31,32,33,34,35 and 36)
INEI – Preliminary results of the Third National Agricultural Census 1994. (Tables 36,41,47,51,53,54,75 and 76).
The percentages refer to each item for all of the agricultural holdings.
* "do not have".
** "do not own tractors".

Centre (CIP) are all actively engaged in improving existing technologies and adapting them to national agricultural conditions (Table 6.6). However, there are still important technological bottlenecks. One problem restricting innovation potential is inadequate government spending on research and technology transfer (Table 6.4).

Referring back to Table 6.1 on yield and area, these findings suggest that while yield increases have been important in augmenting production of most crops, there is much unexploited potential for research to increase yields further. The accumulation of expertise in the agricultural research centres has not reached the majority of farmers. Clearly, the system of disseminating information and research results is one of the culprits in the lacklustre increase in yields and production.

Table 6.6 Comparison of yields (kilograms per hectare)

Product	Experimental Plot	National Average
Rice	9 010	3 170
Soft maize	4 200	1 140
Yellow maize	6 500	2 900
Potato	47 000	8 600
Raw cotton	3 737	1 910

Source: Torero (1992:375, Table 2)

There has been limited progress in mechanization between 1972 and

1994, especially in the highlands and rainforest (Table 6.5). Much of the farmer-owned equipment is traditional. The situation is compounded by inadequate infrastructure and a poor quality irrigation system.

Given that only one in two farmers in the coastal region and one in four farmers in the highlands are using modern inputs, this suggests wide scope for the transfer of new technology. Further, few farmers are using fertilizer and insecticide in sufficient quantities. Case studies by Barrera and Robles (1994) and Gallardo (1994) show that farmers stopped purchases because of financial problems. Reverting to traditional practices has negative consequences on yield and income.

The pattern of access to technology is influenced by many factors, but chief among them is the availability of credit. A general idea of the impact of technical assistance and credit on farmer income can be obtained from the estimates of the National Survey on Rural Households (ENAHR), which indicates the average annual farmer income, in constant July 1984 *intis*, for each region. According to ENAHR, agricultural holdings had higher incomes in all the regions when they had access to credit and technical assistance alone did not guarantee a better economic situation. The ideal scenario is therefore access to both technical assistance and credit. This explains the limited impact of technical assistance in situations where farmers have limited pre-season funds, which directly affect the purchase of inputs, improved seeds and machinery and technical assistance services.

For maize, a UNALM expert identified lack of money as the main bottleneck to production and increasing yield. Farmers simply do not have funds to invest in their crops, which is why they sometimes fail to purchase improved seeds or apply fertilizer in appropriate quantities. The problem is therefore economic and not necessarily technical, as farmers generally do not have money or access to credit to purchase desired inputs (Figueroa, 1988).

The demand for human capital investment: education and technical assistance

The literature on the determinants of agricultural innovation emphasize socio-economic factors such as farm size, risk, human capital, availability of labour, credit and form of land tenure (Feder, Just and Zilberman, 1982; Feder, 1982; Feder and Slade, 1984). In the southern highlands, Figueroa (1986) and Cotlear (1989) identify education as a key factor behind the adoption of new technologies.

Table 6.7 provides a social and economic profile of Peru's farmer population. Between 1972 and 1994, the percentage of farmers without education decreased as farm size increased. However, the proportion of uneducated farmers still accounted for 20.4 percent of farms in 1994. That 59 percent of farmers have only a primary education can be seen as an obstacle to the delivery of extension programmes and technology transfer, which require specialized knowledge on the part of the farmer.

The problems are compounded by regional differences in climate and soils (Velazco and Beteta, 1993). In coastal areas water use is the most pressing concern, as mismanagement results in flooding, land degradation and pest infestation. By-products are soil erosion, lower productivity and ecological disequilibrium. Coastal farmers also have problems with soil fertility, sanitary control and planting for particular crops: rice in Arequipa, Lambayeque and Piura; potato in La Libertad and Arequipa; yellow flint maize in Lima, Lambayeque and La Libertad; soft maize in Arequipa; and cotton in Piura. This lack of technical expertise also affects export crops such as asparagus in La Libertad and fruit in Lima, where yields would be considerably higher if technology were adequate.

In the highlands, given the adverse climate, inappropriate uses of land and forest resources

Table 6.7 Socio-economic profile of Peru's agricultural population

CHARACTERISTICS	YEAR: 1972		YEAR: 1994	
	Farms	Percent	Farms	Percent
Total Agricultural Holdings	1 390 877	100.00	1 742 267	100.00
I. LEVEL OF EDUCATION (Farmers)	1 385 819		1 750 649	
a. None	380 756	27.48*	357 187	20.40*
b. Primary	655 884	47.33*	1 039 598	59.38*
c. Secondary	50 479	3.64*	258 998	14.79*
d. Higher	59 195	4.27*	63 231	3.61*
e. Not stated	231 505	17.28*	31 635	1.81*
II. LAND TENURE				
a. Simple forms				
a.1. Owner	561 242	40.35	1 104 938	63.42
a.2. Tenant	43 625	3.14	40 690	2.34
a.3. Collective	52 180	3.75	397 397	22.81
a.4. Other	231 224	16.62	68 067	3.91
b. Mixed forms				
b.1. Over 50 percent owned	99 811	7.18	68 263	3.92
b.2. Other	94 557	6.80	62 912	3.61
III. LAND USE				
a. Annual crops	967 777	69.58	1 340 647	76.95
b. Permanent crops	126 791	9.12	262 096	15.04
c. Sown pasture	112 730	8.10	176 531	10.13
IV. CROPLAND	1 053 531	75.75	1 671 594	95.94
a. Irrigated	547 334	39.35	792 543	45.49
b. Rainfed	898 886	64.63	1 174 018	67.38
V. AGRICULTURAL LABOUR				
a. Remunerated	447 813	32.20	591 785	33.97
a.1. Casual	422 512	30.38	545 293	31.30
a.2. Permanent	25 301	1.82	46 492	2.67
b. Not remunerated	668 246	48.04	-	-

Source: INEI – Second National Agricultural Census 1972. (Tables 4, 9, 11 and 12)
INEI – Preliminary results of Third National Agricultural Census 1994.
(Tables 2, 26, 27, 29, 30, 33 and 34)
* Represents percentage of total farmers.

have caused land degradation, soil erosion and landslides. Technology needs include: better information on the density and spacing of plants, the use of improved seeds, and disease control and soil fertility. These are of particular concern for soft maize in Cuzco, Cajamarca, Ancash and Junín, kidney bean in Cuzco and Cajamarca, broadbean in Cuzco, potato in Cuzco, Ancash and Junín and fruit crops in Cuzco.

Farmers in the rainforest have to deal with irregular rainfall and increasing deforestation which undermine the ideal conditions for growing tropical products. The technical problems also concern the planting, soil fertility and disease control. They affect economically important crops such as rice in San Martín and Amazonas and yellow flint maize in San Martín.
Any action taken to improve technological practices must take local characteristics and farmer profile into account. Assessment of appropriate technologies is required if local farmers are to overcome their suspicion of technical advice based on the purchase of modern inputs, which increase costs but do not necessarily reduce risk.

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[2] This season was however adversely affected by floods in the North (El Niño) and drought in the South, events that probably underestimated effective demand.

Human capital investment: the supply of technical assistance

Table 6.5 highlights the low percentage of farms receiving technical assistance: 3.41 percent in 1972, 3.6 percent for the 1983 to 1984 season[2] and 9.4 percent in 1994. Although the percentage of holdings receiving technical assistance is very low, this does not necessarily indicate a lack of interest. It may be due to lack of information or economic constraints on the part of the farmer, who may need technical assistance and training but is unable to afford it, particularly in times of economic crisis. There may also be a problem of inadequate quality or insufficient quantity of services supplied.

Statistics show that most technical assistance was provided by the Ministry of Agriculture and the Agrarian Bank in 1972 and 1983-84, while universities, farmer associations, associative enterprises and independent professionals played an insignificant role. The "other" category includes non-governmental organizations and international cooperation and was relatively significant (12.5 percent). In the present context of government restructuring, reduced public expenditure and dissolution of the development bank, the relative importance of public assistance has declined. As a result, in 1994 NGOs have acquired greater importance (12.9 percent), as did independent professionals (19 percent), while the role of the Ministry of Agriculture declined (45.2 percent).

The role of agrarian policy in promoting investment and growth in agriculture

This subsection examines the role of policy on agricultural production in Peru. Special attention is devoted to pricing policy. The 1950s saw a change in pattern of economic growth in Peru and the emergence of new export sectors such as mining and fisheries. The Government encouraged a process of industrial import substitution with significant foreign investment. Macro-economic policy to promote domestic industrial growth created an environment that was hostile to agricultural development, with lower agricultural prices, profitability and dynamism. Agrarian policy under the military government of 1969-1979 had two central themes: agrarian reform and low-cost urban supply (Alvarez, 1983).

The APRA[3] government that took power in 1985 viewed the agrarian problem as one of low agricultural profitability and introduced a series of measures to raise farm prices, lower costs and increase productivity. Large sums were allocated to subsidize credit and basic inputs, such as fertilizer and pesticide. The results were good until 1987 when the symptoms of failed economic management affected agricultural performance. The leading beneficiaries of this policy were the modern agricultural holdings in the coastal and rainforest regions. The coastal region accounted for 74.1 percent of fertilizer sales and subsidized credit was overwhelmingly directed towards coastal and rainforest crops such as cotton and yellow flint maize. Fertilizer prices fell in real terms until the end of 1988. The highland benefited minimally from these policies (Velazco, Velazco and Sulen 1990).

The populist policies of 1985 to 1990 increased aggregate demand and pushed up imports, triggering a fiscal deficit in 1988/89 and a balance of payments crisis that in turn caused hyperinflation and recession. To quote Gonzales (1996:25), "the impact on agriculture and smallholders was negative in this period since what had been gained in the first years of the APRA government was lost in the last two years, culminating in greater impoverishment than had existed in 1985".

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[3] APRA (Alianza Popular Revolucionaria Americana), Peruvian political party founded in the 1920s by Víctor Raúl Haya de la Torre and forming government for the first time in 1985-1990 under Alan García Pérez.

The programme of stabilization introduced in the early 1990s to bring inflation under control was based on restricted control of monetary variables, readjustment of prices and public tariffs, elimination of subsidies, increased taxation, reduction of public expenditure and the free movement of exchange and interest rates. These measures were underpinned by a package of structural reforms aimed at efficient resource management through market deregulation and liberalization and a reduced entrepreneurial role of the state through privatization and the closure of monopoly concerns. The latter included PESCA PERU (a fish corporation), CPV (*Compañía Peruana de Vapores*), ENCI and ECASA (*Empresa Comercializadora de Arroz Sociedad Anónima*) (León, 1994; Mendoza, 1992; Dancourt and Mendoza, 1994).

The policy measures affecting agricultural performance included the removal of subsidies and price controls for agricultural products and inputs and their unrestricted marketing for export. Variable import tariffs were introduced to provide a degree of protection against the subsidies of the main exporting countries and exchange rate lags (Dancourt and Mendoza, 1994). The tariff surcharge in 1995 on commodities such as wheat and sugar was zero.

In the financial market, interest rates were freed and loans to the agricultural sector declined seriously following the dissolution of the Agrarian Bank of Peru (BAP). The Bank had already begun to reduce its credit operations in the 1988/89 season when it provided funding for 800 000 hectares versus 1 200 000 hectares in the previous year (Escobal, 1989). The situation was particularly acute among small farmers, where only 7.6 percent had access to BAP credit in 1984 (Portocarrero, 1987). This is indicative of the importance of the informal sources of credit and of the impact on interest rates. The credit situation worsened with the demise of the Bank and the rise in interest rates. Coastal farmers were the most affected since BAP funding had been biased towards their products. For example, from 1980 to 1988 average funding for cotton amounted to 22.6 percent of total loans, while rice accounted for 32.2 percent of allocated funds (Agrarian Bank, selected annual reports).

The restriction of credit through the BAP led to a restructuring of agricultural lending. During 1986 to 1990, 88 percent of bank credit for agriculture was from the BAP and 22 percent from the Banca Comercial, whereas in 1991 the BAP accounted for 25 percent and the Banca Comercial 75 percent. In 1992, the latter was the only bank operating in the sector. However, the sums involved were relatively small: US$92.5 million in 1992, US$131.3 million in 1993 and US$202.7 million in 1994, compared to US$ 789.7 million in 1989 (Bank and Insurance Authority, reports).

Given the limited involvement of the Banca Comercial in agriculture, the Government set up the Fondeagro (*Fondo para el Desarollo Agrícola*), which provided US$280 million in loans from 1992 to 1994. Village banks were also formed. Data from Corporación Financiera de Desarollo (COFIDE) and the Bank and Insurance Authority indicate US$587.6 million in agricultural lending from 1993 through November 1994, with 56.3 percent provided by the Banca Comercial, 1.4 percent by village banks and 42.3 percent by Fondeagro and revolving funds. The efficiency and effectiveness of the credit institutions set up to fill the vacuum left by the BAP have not been assessed.

The liberalization of the financial market led to the elimination of the preferential rates of interest charged by the BAP, increasing financial costs to farmers. The real quarterly lending rate rose from –34 percent in the third quarter of 1990 to 4.3 percent in the first quarter of 1991. Banca Comercial real interest rates for the same quarter in 1993 and 1994 were 4.4 percent and 5.1 percent respectively (BCR, selected issues).

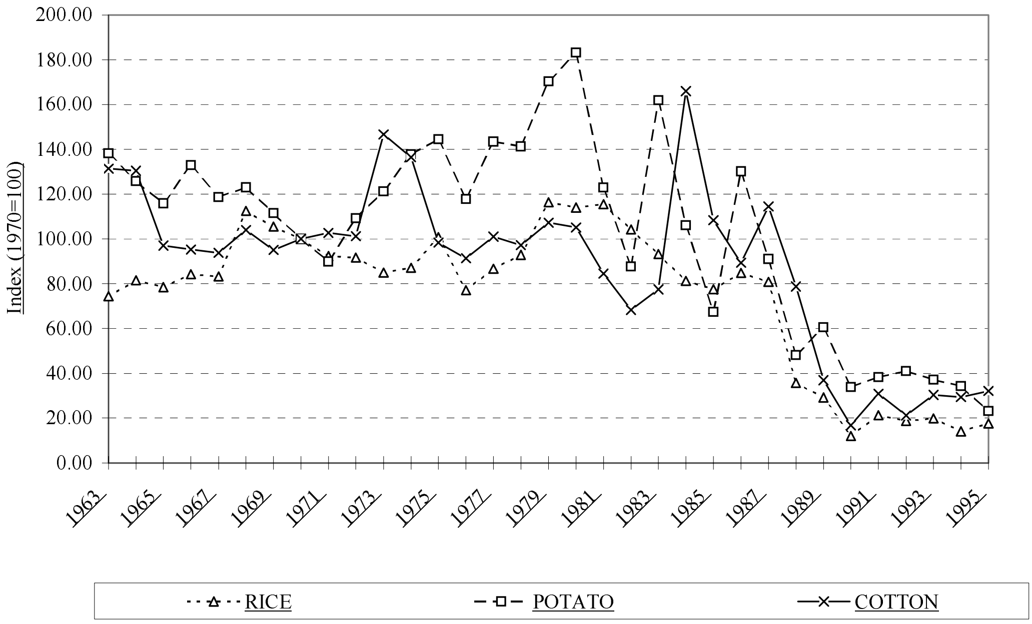
In December 1995, the Government introduced the Special Taxation Program (PERT) which provided farmers, livestock producers and agribusiness with easier terms for tax payments due 31 December 1994. The Program also exempted three forms of taxation (sales tax, income tax, municipal and development tax) for farmers whose annual sales did not exceed 50 taxation units for the 1995 financial year (Arias, 1995).

At the same time, the main institutional reforms in the agricultural sector were the liberalization of the property market, water and the ending of state monopolies such as ENCI and ECASA. The Land Act of 1995 removed size limits on property and permitted the privatization of land belonging to peasant and indigenous communities. Another important reform pending is the Water Act, which would define rights of water ownership. Yet another law in the pipeline concerns natural resources (Alerta Agraria, selected issues).

The Role of Agricultural Prices in Stimulating Investment and Growth in Agriculture

State intervention in agricultural markets dates from 1939 (Alvarez 1983) when the aim was to

FIGURE 6.2
Changes in Peruvian farmgate price indices adjusted by the consumer price index



promote the cultivation of products such as pulses and rice. Pricing policy under the military government of 1969 to 1979 was essentially geared towards reducing the cost food to urban consumers, with measures to control and regulate food prices. Figure 6.2 traces price changes of rice, potato and cotton . It indicates a slight increase in the 1960s and late 1970s, fluctuations in the early 1980s and a downward trend until the 1990s.

The most important consequences for agriculture of the new macro-economic environment starting in 1990 have been a significant fall in production and prices of both tradable and non-tradable products. Escobal (1994) found that agricultural earnings for 1992/93 were down 61 percent from 1989-90. When identifying the effects of the Program of Stabilization and Structural Adjustment on agriculture, it is essential to take into consideration the initial conditions of the sector and the effect of events that cannot be controlled, such as natural disasters and climate change, but affect agricultural production. Historically, the agrarian crisis in Peru can be dated back to the 1970s when production increases failed to keep pace with population growth (Hopkins, 1981).

The noteworthy characteristic of this situation in the 1990s is that earnings in both tradable and non-tradable agriculture have been affected. The terms of trade deteriorated because of more expensive credit and climate change, which directly impacted production conditions. In addition, the determining factors of demand, reduced employment and income appear to have reduced the capacity to purchase agricultural products (Dancourt and Mendoza, 1994).

The impact of the macro-economic context on agricultural production can be illustrated by examining the effect on production. Production declined 5.5 percent between 1989/90 and 1990/91, 26 percent between 1990/91 and 1991/92 and 8.4 percent between 1991/92 and 1992/93 (Statistics Bulletin of the Ministry of Agriculture: selected years), along with a similar pattern in cropped area.

The impact of political violence on agricultural investment and growth

Peruvian society was deeply affected in the 1980s by two important factors: the economic crisis that led to recession and hyperinflation and the spread of political violence that embraced most of the country, especially the rural sector. The peasant farmer population noted the economic crisis in the changing terms of trade and in the depressed labour market with fewer work opportunities and lower wages. These were the two largest determining factors of income generation and consumption in rural households. Another important element of the macro-economic context was the introduction of a policy of stabilization and extensive structural adjustment. The economic crisis and political violence can be seen as external events that changed the economic, social and political structure of the rural sector.

Over 30 000 people are estimated to have died during the "dirty war" waged by the Shining Path, the *Túpac Amaru* Revolutionary Movement, para-military groups and the armed forces. The urban areas most affected by subversive activity were, in order of importance, Ayacucho, Junín, Huancavelica, Apurímac, Puno, Cusco and Lima. One of the direct consequences of the violence was population displacement to other provinces in the department and to more distant urban areas, particularly Lima, Huancayo, Ica, Huamanga and Abancay.

Most of the migrants were rural inhabitants. Coral (1994) found that middle income and wealthier rural people tended to move to distant destinations such as Lima, Ica or Huancayo. Where the risk was not so great, families moved to intermediary towns and department capitals, provinces or rainforest areas. In contrast, poor people either remained in their communities or moved to small nearby communities.

Although the fighting occurred in the central-southern highland and in the rainforest, the political violence affected all of Peruvian society. Coronel (1997) lists the following consequences: 25 927 dead, 6 000 disappeared, 430 075 displaced, 1 600 000 directly affected and 9 000 lost complete freedom and rights.

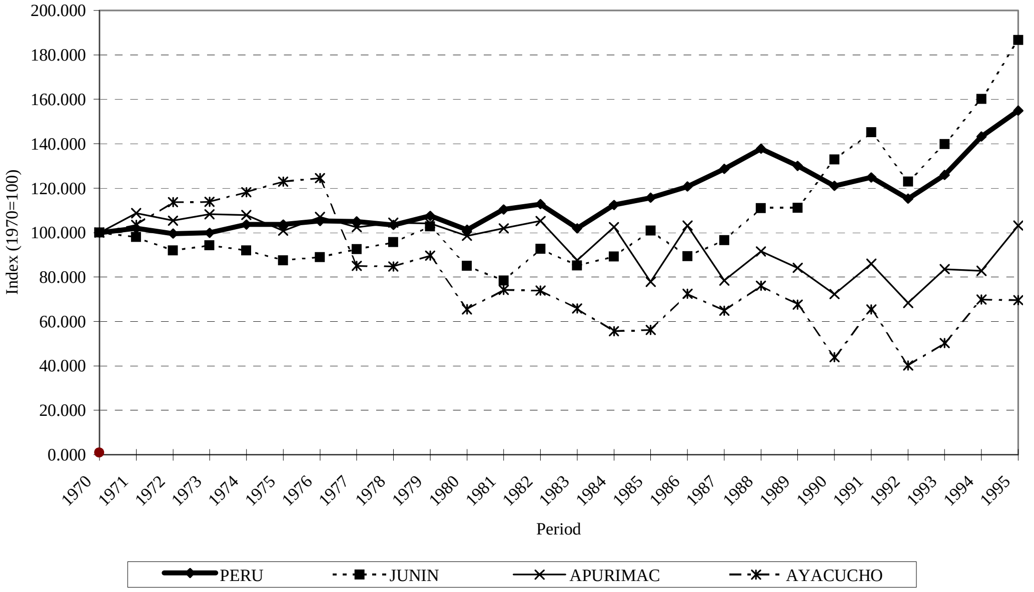
Most acts of political violence in the departments of the central region occurred in Ayacucho, which accounted for 43 percent, followed by Junín with 34 percent. Among civilian casualties, 69 percent were peasant farmers (SEPAR, 1992:15,36). In addition, the political violence had the following negative effects: disinvestment; low productivity; destruction; loss of technology and stock; disruption of market infrastructure; material destruction of production infrastructure, services and roads;

Table 6.8 Coefficients of simple correlation, 1970-1994

Variables	Coefficient
Private investment and political violence	-0.56 (-3.25)*
Public investment and political violence	-0.03 (-0.143)
Investment in agriculture and political violence	-0.48 (-2.62)*
Investment in machinery and political violence	-0.28 (-1.4)

Note: The values in brackets are the t-statistics
*= five percent significance level
Source: Webb and Fernandez Baca. 1995. Compiled by the author.

FIGURE 6.3
Evolution of agricultural GDP in Peru and in Departments affected by political violence



decline in public and social institutional presence; and an increase in drug trafficking. In response, new forms of organizations have emerged to deal with these problems, such as defense committees and women's associations (Coronel, 1997).

Estimates of simple correlation coefficients between private and public investment in agriculture and the number of subversive actions recorded by the National Police (Instituto Cuanto, 1995) show a negative relationship between acts of political violence and investment (Table 6.8). Figure 6.3 compares agricultural GDP in the departments most affected by the political violence (Junín, Apurímac and Ayacucho) and agricultural GDP in the country as a whole. The graph shows that political violence in rural areas adversely affected agricultural development from its outbreak in the early 1980s, leading to lower agricultural GDP in Ayacucho and Apurímac. This was followed by recovery in the early 1990s during the relatively successful process of national pacification. The GDP in Junín differed from that in the other departments because most of the food supplies for the seven million inhabitants of the city of Lima come from the valley of Mantaro in Junin and also because more severe military actions occurred in the southern highlands and the rainforest.

The problem now facing the areas hit by political violence is rehabilitation and reconstruction. Young returnees to a conflict-hit community of Apurímac, one of the poorest parts of the country, indicated that they needed credit and technical assistance (Rodríguez, 1997).

Impact of external debt on agricultural investment and growth

A glance at economic fluctuations during the period from 1959 to 1996 shows six recessions, five coinciding with external factors such as

Table 6.9 Coefficients of simple correlation, 1970-1994

Variables	Coefficient
Private investment and external debt	-0.51 (-2.86)*
Public investment and external debt	0.104 (0.5)
Investment in agriculture and external debt	-0.41 (-2.16)
Investment in agriculture and inflation	-0.24 (-1.18)

N.B.: The values between brackets are the t-statistics
* = five percent significance level
Source: Webb and Fernandez Baca (1995). Lima: Instituto Cuanto S.A.
Compiled by the author

deterioration in the terms of trade, increase in international interest rates and/or reduced availability of external credit (Dancourt, Mendoza and Vilcapoma, 1997). The coefficients of partial correlation between investment, external debt and inflation (Table 6.9) suggest that private investment is more sensitive to changes in the macro-economic context than public investment or investment in agriculture.

However, the impact on agri-cultural investment may be indirect. Twomey's study (1989) of the external debt crisis in Latin American found that the payment of debt affected import capacity which, in turn, impacted directly on agriculture and decreased production because of the lower availability of hard currency for fertilizer imports. The author also found that restrictive monetary policy reduced the supply of credit to the agricultural sector.

6.3 Restrictions to agricultural investment and growth: a regional perspective

The 1990s have been a period of fundamental change in agricultural performance. Implementation of the stabilization programme and structural reforms has modified the institutional context and the conditions in which agricultural producers participate in the market. The following section puts forward a number of hypotheses and explanations as to how the new economic rules at national level have affected micro-economic decisions in agriculture.

For ease of analysis, farmers have been divided into those producing for export and those supplying the domestic market. Each category is further divided between those who have performed badly and those who have adapted successfully to the new market conditions.

Farmers in the greatest difficulty

When examining the impact of adjustment policies on small-scale commercial agriculture which had no or limited diversification, Escobal (1994) found that the farmers of Serrán and Malacasi in the Alto Piura were seriously hurt. The medium and small commercial fruit growers of Motupe, Olmos and San Lorenzo in Piura were also hard-hit, especially since they had no access to credit. The rice farmers of Ferreñafe, Lambayeque also suffered a collapse of income despite selling part of their livestock and equipment.

A different case study by Barrera and Robles (1994) includes the results of the Organización Nacional Agraria (ONA) coastal survey of 20 farmers growing asparagus and yellow flint maize in the valley of Chicama in the coastal department of La Libertad. One important finding was that, although there was a greater supply of agricultural inputs, farmer demand for inputs fell because of lower real farm-gate prices and higher credit costs.

These trends are corroborated by the first agrarian survey conducted by the Ministry of Agriculture from 31 August to 8 September 1993 among 2 931 farmers in the valleys of Chira, San Lorenzo, Alto Piura, Medio Piura and Bajo Piura. The survey figures show that 52 percent of farmers did not use inputs in sufficient quantity and of adequate quality because of high prices. The main problems facing agriculture were lack of credit (82 percent of respondents), shortage of water (55 percent) and high input prices (42 percent) (CIPCA, 1994).

The same survey in 72 irrigated coastal areas in June through December 1993 in the departments of Tumbes, Piura, Lambayeque, La Libertad, Ancash, Lima, Ica, Arequipa, Moquegua and Tacna produced similar results. One of the principal reasons for leaving arable land uncultivated was the precarious economic situation in which small and medium farmers found themselves, a situation compounded by shortage of water and lack of access to credit.

The rice growers of Arequipa are a good example of how farmers react to difficult conditions.

The large decrease in some farm-gate prices made them turn to other more profitable crops . This "crop conversion" (*El Comercio*, 1995) involved growing marigolds for export and planting annual crops, such as sweet potato, onion, garlic and soft maize in valleys that were clearly suited to rice-growing such as Tambo, Majes, Ocoña and Camaná.

The 1993 agrarian survey of farmers in 72 coastal valleys revealed the existence of partnerships between farmers and processors to promote a particular product. For example, rice and wheat millers provided credit for inputs on the condition that they could then purchase the farmer's harvest at pre-set prices. (SINIA, 1993). Among export crops agreements evolved between farmers and exporters who provide credit for the cultivation of marigold, asparagus, sorghum and sunflower. Further study is needed on the results of these contracts to determine whether they have been beneficial to farmers. In the case of marigolds in Aplao, Valley of Majes, yields per hectare and hence income have been lower than anticipated, because of inadequate technical assistance.

In other cases, the problems of small farmers in funding their cropping activities and engaging wage labour have given rise to new practices such as that observed in the department of Piura where labour is exchanged between relatives and/or friends (Zevallos, 1994). The immediate consequence of this practice has been to slash demand for labour and make it even harder for landless labourers to find work. The author also identified another strategy used by small landowners which was to lease their land and sharecrop. Such agreements have mainly been made with agribusiness corporations and have in effect turned farmers into wage earners on their own land. In terms of land area, this practice is most prevalent among medium-size farms. In terms of numbers of leaseholders, it is most prevalent among smallholders.

Coping mechanisms of peasant farmers

The availability of off-farm activities has helped diversify sources and averted sharp declines in peasant farmer income. For farmers in the Napo River basin, in the rainforest department of Loreto, this has meant prioritizing extractive activities. In the highland department of Cusco, in the upper Urubamba valley, Cavassa, Carpio and Gómez (1992) showed that the strategy adopted by farmers was to produce seed potato instead of potato for consumption.

In addition, the impact of adjustment on the peasant farmer communities of Pomacanchis revealed that the changes in relative prices had significantly affected the pattern of demand for inputs and factors of production, as well as yields. Modern inputs and factors of production have been replaced by more traditional methods (Gallardo, 1994).

A study of four small settlements in Bambamarca, in the rural province of Cajamarca, found that the most affected were the very poor who had limited access to land and who were net market purchasers, sellers of handicrafts and livestock producers (Velazco and Caballero, 1996). The study concluded that the most effective peasant strategy to mitigate the impact of the structural adjustment programme was to diversify, increase autoconsumption and seek wage labour. Families who did not diversify their agricultural production were more affected by structural adjustment than those producing a range of items. Increasing autoconsumption and decreasing purchase of market goods gave families the material means to absorb the adjustment. Thus, the decline in farm prices and income was accompanied by reduced demand for purchased goods such as rice, oil, detergents and salt. Finally families reduced their reliance on cash crops and increased off-farm income through petty trade and urban wage labour.

Farmers with relative success

The more successful farmers were involved in the non-traditional agricultural export sector. Production organization and linkage with agribusiness facilitated this success. Those more directly involved in agricultural exports have been coastal farmers, while the sierra and rainforest farmers have been largely bypassed. The change in composition of agricultural exports indicates that the share of traditional exports fell from 97 percent in 1970 to 34 percent in 1993. The primary non-traditional exports are asparagus, fruit, pulses, canned goods, olives and flowers. Escobal (1994) discovered that medium and large commercial producers of green asparagus in Chincha posted good production performance thanks to access to funding and guaranteed demand that enabled them to maintain and raise their incomes. The case of asparagus is particularly important, as its share of non-traditional agricultural exports rose from 7.8 percent in 1980, 15 percent in 1985, 35.3 percent in 1990, to 47 percent in 1992. The average annual rate of growth of asparagus exports for the period 1980-1993 was 24 percent and the annual rate of growth of cropped area for 1970-1993 was 19.7 percent (Compendium of Agricultural Statistics, 1994). A 1993 survey by the Ministry of Agriculture indicates that asparagus is cultivated on 7.1 percent of cropland in La Libertad and 3.2 percent of Ica.

The expansion of coastal agricultural exports has not been without difficulties in adapting to the new economic context. Fieldwork by Marañon (1994) in the valleys of Chao and Virú in the coastal department of La Libertad indicated that large holdings employed modern technology and tended to specialize. In contrast, small farmers were faced with constraints to innovation. For example, a small export concern in Piura shipping frozen green pigeon peas to the United States drew up production agreements in 1992 with small farmers to meet the demands of the international contractor. However, getting these farmers to adopt new cropping practices was not easy. While production costs and water usage are lower than for traditional crops, farmers lacked commercial experience and technical knowledge. This was compounded by lack of technical assistance, funding and faith in the market for the product (Olaechea and San Miguel, 1993).

Asparagus operators had similar problems when they started to promote activities in the valleys of Chira and Cieneguillo. The processors found that they needed to provide much more than seed. Technical assistance with harvest and post-harvest handling proved to be the lynchpin to maintain quality and prices (Olaechea and San Miguel, 1993).

Flower exporters belonging to the Exporters Association (ADEX) Committee on Flora and Fauna showed that the surface area planted in flowers could be increased from 200 to 400 hectares with a positive impact on foreign exchange earnings and absorption of human resources, currently employing 2 500 families. They sought a reduction in airfreight charges and called for the producers, exporters and the State to collaborate in research and access to the latest technology. Rather than subsidies, they asked the State for macro-economic policies that promote exports (*El Comercio*, 1995).

The Agricultural Census of 1994 identified the main restrictions to farming. Over 16 percent of farmers reporting uncultivated land. The reasons were: 74 percent lacked water, 61 percent lacked seed, 49 percent lacked credit, 31 percent lacked labour, ten percent had problems with salinity, erosion or poor drainage and four percent were obstructed by terrorism. The primary reason for lack of water is the absence of infrastructure. To counteract some of these problems, investment by the Compensation and Social Development Fund (FONCODES) in resource-poor rural areas includes small irrigation schemes, as well as forestation and reforestation programmes, soil rehabilitation and marketing infrastructure.[4]

A second group of reasons for failure to cultivate land includes farmers' economic status

[4] For the period January-September 1997, 14.3 percent of FONCODES project investment was for agricultural purposes, with an emphasis on small irrigation schemes (Office of the President of the Republic, 1997).

and macroeconomic policies with adverse impact on agriculture. Limited access to credit or poor returns make it difficult to acquire seed and fertilizer, make farm improvements, purchase machinery, accede to modern technology packages and technical services, or hire wage labour.

A potential problem among the more successful farmers was the relative concentration of processors. From 1986 to 1994 the number of mango export companies fell from 47 to six (Gómez 1995). Marañon (1991) found high levels of processor concentration for exported canned asparagus in Trujillo, Huaral and Lima, maracuya juice in Chiclayo, Chanchamayo and Piura and flowers in Callejón de Huaylas. For example, four companies accounted for 80.3 percent of the canned asparagus. One company accounted for almost half of the export market of marcuya juice, while four companies processed 88.4 percent. Market concentration was even higher among flower exporters; one company accounted for over three-quarters of total exports. The author attributed their position to membership in regional or national entrepreneurial groups investing in agribusiness, which provided funding and technology transfer.

6.4 Models of growth in Peruvian agriculture

To quantify the relative importance of such factors as land, capital and labour discussed in section 6.2, models of agricultural production and supply are estimated. Using cointegration techniques, a model of aggregate agricultural production is estimated. Since potato, rice and cotton are major crops, aggregate supply functions are also estimated.

Estimation of production functions

The following Cobb-Douglas production function was estimated for Peruvian crops.

$$\text{Ln}(Y_t) = a_o + a_1 \text{Ln}(T_t) + a_2 \text{Ln}(L_t) + a_3 \text{Ln}(F_t) + a_4 \text{Ln}(M_t)$$

where Y is value of agricultural GDP at constant 1979 soles, T is cropped area in hectares, L is labour measured as the economically active population involved in agriculture, F is aggregate consumption of a range of fertilizers and M is the stock of machinery measured by the number of tractors, with observations by time, t. The coefficients a_i $(i=1,..4)$ are the elasticities of the respective variables with respect to agricultural production, with the assumption that $a_i > 0$. Translog production functions were estimated but multicollinearity hampered estimation of the coefficients of regression.

FAO data wereused for all variables. Although there are informational shortcomings in, for example, the summation of fertilizer variables, the calculation of agricultural EAP and the failure to allow for machinery depreciation, the estimated functions do give an indication of the relative importance of these factors in agricultural production.

Given this is time series data, stationarity tests were conducted and the production function was estimated using the cointegration method suggested by Johansen (1988) for the period 1970-1995. Under this methodology, two or more variables can be considered to be in long-term equilibrium if they move closely and in parallel over time, even though they may momentarily move in opposite directions. For this reason, the technique is particularly useful to identify the determining factors of output. The long-term relationship is known as the cointegration vector.

An augmented Dickey-Fuller (ADF) test that the variable levels are integrated in single order was not rejected. Moreover, the null hypothesis that the first differences have unit roots was rejected. The Trace test indicated at most two cointegration vectors using Johansen and

Juselius' (1990) criterion and one cointegration vector using Reimers' (1992) criterion. The maximum characteristic value test showed there were at most two cointegration vectors.

The resulting normalized cointegration vector provides an estimate of the relative contribution of land stock, agricultural labour, fertilizer and machinery to Peru's agricultural output.

$$\text{Ln}(Y) = 0.76\text{Ln}(L) + 0.24\text{Ln}(T) + 0.10\text{Ln}(F) + 0.06\text{Ln}(M)$$

What stands out is the magnitude of the elasticity of labour; a one percent increase in agricultural labour would have the greatest impact on boosting production, 0.76 percent, followed by land, fertilizer and tractors.

By way of comparison, Twomey (1989) estimated aggregate Cobb-Douglas production functions for Latin America for 1969-1982, using FAO data on fertilizer, land and tractors as independent variables. Estimates of the elasticities of agricultural supply for fertilizer use were between 0.1 and 0.2; for land (arable plus permanent cropland) 0.44 and 0.58; and for tractors the estimated values fluctuated between 0.18 and 0.39. Agricultural labour data were not included.

Table 6.10 Estimation of supply functions for Peruvian crops, 1970-1995

Explanatory variables	Cotton (Model 1)	Cotton (Model 2)	Rice	Potato
Intercept	8.254 (10.75)*	8.253 (11.02)*	8.005 (5.43)*	7.754 (7.26)*
Price cotton (t-1)	0.467 (5.77)*	0.465 (5.76)*		
Price rice (t-2)			0.284 (1.46)**	
Price potato (t-2)				0.229 (1.51)
Invmac (t-2)				0.06 (1.36)
Invlimp (t-2)	0.005 (0.10)		0.087 (1.01)	
Credit (t-1)	0.034 (1.23)	0.034 (1.26)		0.012 (0.67)
Climate			-0.005 (-0.15)	
Climate (t-1)	-0.268 (-5.56)*	-0.268 (-5.72)*		-0.083 (-2.47)*
AR(1)	0.664 (3.55)*	0.665 (3.55)*	0.893 (6.63)*	0.273 (1.27)
R^2	0.863	0.863	0.628	0.55
Adjusted R^2	0.826	0.835	0.545	0.418
F-Statistic	22.84	30.13	7.603	4.16
Durbin Watson	1.67	1.66	2.33	1.82

* Significant at five percent

** Significant at ten percent

Note: The variables are expressed in logarithms, t-statistics are given in parentheses.
Source: MAG, Compendio Estadistico Agrario, various years.
Price cotton (t-1): Price of cotton in the previous year.
Price rice (t-2): Price of rice two years prior.
Price potato (t-2): Price of potato two years prior.
Invmac (t-2): Investment in machinery two years prior.
Invlimp (t-2): Investment in land improvement two years prior.
Credit (t-1): Credit in the previous year.
Climate (t-1): Climate in the previous year expressed as a dummy variable which refers to the serious presence of the El Niño current.

Estimation of supply functions

Building on the previous analysis, the economic factors in determining the supply of cotton, rice and potato are now discussed, using the following supply function:

$$\text{Ln}(Q) = a_o + a_1 \text{Ln}(Price) + a_2 \text{Ln}(Credit) + a_3 \text{Ln}(Investment) + a_4 Climate,$$

where Q is agricultural supply, *Investment* is investment in land improvements and agricultural machinery, *Price* is the average real commodity prices and *Credit* is the amount of credit for the product from the financial system. The variables in the model are expressed in logarithms so the coefficients a_i can be interpreted as elasticities. *Climate* is added as a dummy variable to account for severe climate anomalies such as *El Niño* in 1981 and 1991. Incorporating a dummy variable for the number of terrorist attacks proved intractable because of low occurrence. The data source is the Statistical Compendium of the Ministry of Agriculture (MAG, selected years).

The models (Table 6.10) explain a substantial portion of the variation in each crop supply (42 to 84 percent). The elasticity values are within expected values. The supply levels are affected by the price of commodities in previous years and the climatic conditions in the previous season. The coefficients of agricultural investment, whether in land improvement for cotton and rice or in machinery for potato, have the expected positive signs but limited statistical significance. This may reflect the limitation of the variable used, since it does not account for accumulated capital stock.

6.5 Conclusions

This chapter has looked at the evolution of sources of growth in Peru's agricultural sector, in particular, we have looked at how changes in land, labour and fertilizer, the role of public and private investment, technological change, policy and political violence have influenced Peru's agricultural sector. The difficulties facing farmers in the present post-adjustment context and examination of strategies that have been most successful were examined. Finally, in an attempt to quantify the contribution of different factors to Peruvian agriculture, aggregate agricultural production function and supply functions were estimated. From this analysis, the following conclusions can be made.

While there was a 51 percent expansion of cultivated area between the censuses of 1972 and 1994, land is still concentrated in larger holdings. Although the Agrarian Reform collectivized land into farmer groups, the present agrarian structure is predominantly made up of small farmers, who account for 77 percent of the total farmer population, have holdings of less than five hectares and work 6.56 percent of the agricultural area. In contrast, 2.9 percent of the farmer population have holdings of more than 50 hectares and account for 70.4 percent of the total agricultural area.

While the economically active population engaged in agriculture appears to have grown by an annual 0.81 percent between 1970 and 1995, a large proportion has little or no education. The 1994 census indicates that 20.4 percent of farmers have no education, 59.4 percent primary education, 14.8 percent secondary education and only 3.61 percent higher education. Thus human capital investment would appear to be an obstacle to the effectiveness of extension programs and to technological change.

The use of improved inputs is concentrated in the coastal region. It is the greatest consumer of fertilizer, with the rainforest and highlands following far behind. Demand for tractors and agricultural machinery is also concentrated in the coastal region, with very limited demand in the highlands and rainforest. Technology use, particularly fertilizer use, has fluctuated according to availability of foreign currency, international prices and exchange rate policy.

Regional analysis of production growth rates in terms of cropland and yield for the major crops indicate no significant leaps in production or sweeping technological change between 1970 and 1995. The significant differences between yields from demonstration plots and farm plots suggest considerable scope for effective technology transfer. Given the erratic nature of public investment in agricultural research in Peru, it proved to be relatively insignificant. Clearly, such investment needs to be more consistent and target a wider range of producers.

As regards macro-economic indicators for 1970-1995 and agricultural investment, the period of overall economic growth was not matched by growth in the agricultural sector. On the other hand, public and private investment expanded most during this period (1970-1975) and thereafter generally declined. The bulk of public investment has been directed towards land improvement (73 percent), largely in the form of large-scale irrigation works in coastal areas. The 1994 Census identified the absence of adequate irrigation infrastructure as a major constraint to capital investment. Meanwhile, private investment has focused on establishing perennial crops, livestock production and the purchase of agricultural machinery. Limited access to credit appears to be a major obstacle to buying equipment, as well as purchasing seed, fertilizer and agricultural services.

There appears to be a relationship between public and private investment, with the latter responding to increases in the former. Given the risks inherent in agriculture, private operators may be more prone to invest in the sector once the Government has provided irrigation infrastructure or expanded cultivable land.

Macro-economic and agricultural policies have reduced profitability, with a relative fall in agricultural prices. The situation for farmers was compounded by the political violence of the 1980s in mainly rural areas. This led to sharp decreases in agricultural production in the central and southern highlands and the increasing poverty among the peasant farmer population.

Agricultural investment has been adversely affected by periods of high inflation, the external debt crisis and hence lower availability of funds and political violence, with its attendant risk and uncertainty and the loss of human, material and production capital.

Looking at regional differences and coping-mechanisms of farmers gave widely differing indications of the impact of structural adjustment on agriculture and farmers. Those producing for the domestic market were the most affected because of lower prices due to decreased demand and higher production costs. Farm holdings that diversified their sources of income mitigated the problems of lower profits by raising the contribution of off-farm income. Farmers growing for the export market fared relatively better as they had guaranteed access to credit, received high external prices and were well organized.

With respect to the key components of agricultural growth in Peru, estimation of the aggregate production function for 1970-1995 indicated that increasing agricultural employment would have the greatest impact on output, followed by land, fertilizer and tractors. A ten percent increase in labour *ceteris paribus* would have increased production by 7.6 percent, while similar increases in cultivated land area, fertilizer use and tractor use would increase production by 2.4 percent, one percent and 0.6 percent, respectively.

Estimation of the supply functions for cotton, rice and potato revealed the relative importance of expected price and climate conditions compared to credit and investment in land improvements and machinery. The implication is that profitable and favourable conditions for agriculture must exist to encourage investment.

From all these findings the following causal relationships can be inferred between agricultural investment and growth. Agricultural output is a function of cultivated area, labour, fertilizer and machinery. Cultivated area is a function of public investment. Private investment in machinery *et cetera* is a function of both credit availability and prior public investment in infrastructure and land improvements. Technological transfer is dependent upon agricultural research and extension, which is a function of both public and private investment. Public investment is a function of taxes collected, external shocks, external debt and social stability.

These relationships indicate that an increase in agricultural production requires an increase in production factors, but that this will only occur if public and private investment take place. Since public investment drives the latter, it is a crucial to expanding output. In addition, they are both necessary to develop technology through agricultural research. Clearly, macro-economic and external conditions and internal stability factors such as the political violence of the past decade have a strong bearing on agricultural investment performance.

References

Alerta Agraria. Various years. Monthly magazine, various issues. Lima.

Alfaro, J., Monge, C. & Figueroa, A. 1997. *Pequeña agricultura en el Perú: presente y futuro*. Lima, PACT-Perú.

Alvarez, E. 1974. La agricultura alimenticia peruana, 1960-1970. Thesis, Social Science Program, Pontificia Universidad Católica del Peru, Lima.

Alvarez, E. 1983. *Política económica y agricultura en el Perú: 1969-1979.* Lima, IEP.

Amat, C. & Leon, C. 1996. *Seguridad alimentaria*. Lima, Centro de Investigacion de la Universidad del Pacifico (CIUP), Cuadernos de Investigación.

Arias, C. 1995. Sube la producción, baja los precios. *Actualidad Economica,* 17(162): 22-23.

Banco Agrario. 1991. *Memoria 1990*. Lima, Banco Agraria.

Barrera, M. & Robles, M. 1994. Impacto de la política económica en unidades agrarias. los casos de Ancash, La Libertad y San Martín. In Dancourt, Mayer & Monge,eds. *Perú: el problema agrario en debate. SEPIA V.* Lima.

Barro, R. 1990. Government spending in a simple model of economic growth. *Journal of Political Economy*, 98(5).

BCR (Banco Central de Reserva del Peru). Various years 1990-1995. *Nota Semanal*. Lima, BCR.

Cavassa, A., Carpio, O. & Gomez, H. 1992. El impacto de los proyectos de desarrollo en la sierra: el caso de PRODERM en la cuenca de Pomacanchi-Cusco. Cusco, Peru, Centro de Estudios Regionales Andinos Barolome de las Casas.

Censo Nacional Agropecuario II, 1972. 1975. Resultados definitivos a nivel nacional. Lima, Presidencia de la Republica, Oficina de Estadisticas y Censos.

Censo Nacional Agropecuario III, 1994. 1996. Resultados definitivos: Peru. Lima, INEI.

CIPCA. 1994. Report of Centro de Investigacion y Promocion del Campesinado (CIPCA), Piura. *Reporte Agrario* 10 (May-June).

Coral, I. 1994. *Desplazamiento por violencia política en el Perú, 1980-1992.* Lima, Centro de Promocion de Desarrollo y Poblacion-Instituto de Estudios Peruanos (CEPRODEP-IEP). Documento de Trabajo.

Coronel, J. 1997. Balance por desplazamiento de la violencia política en el Perú, 1980-1997. Paper given at Seminario Permanente de Investigacion Agraria (SEPIA) VII, Huancayo.

Cotlear, D. 1989. *Desarrollo campesino en los Andes*. Lima, IEP.

Dancourt, O. & Mendoza, W. 1994. Agricultura y política de estabilización en el Perú. In Dancourt, Mayer & Monge, eds. *Perú: el problema agrario en debate. SEPIA V.* Lima.

Dancourt, O., Mendoza, W. &. Vilcapoma, L. 1997. *Fluctuaciones económicas y shocks externos, Perú 1950-1996.* Lima, PUCP, Documento de Trabajo No. 135, CISEPA.

Dutt, A. 1991. Stagnation, income distribution and the agrarian constraint: a note. *Cambridge Journal of Economics*, 15.

El Comercio. 1995. Wednesday, 29 March 1995. Section E10.

Escobal, J. 1989. *Políticas de precios y subsidios agrícolas: impactos macroeconómico y sectorial. Perú 1985-1989* Lima, GRADE, Documento de Trabajo No.5.

Escobal, J. 1994. Impactos de las políticas de ajuste sobre la pequeña agricultura. *Debate Agrario*, 20 (December).

Feder, G. 1982. Adoption of interrelated agricultural innovations: complementarity and the impact of risk, scale and credit. *American Journal Of Agricultural Economics.*

Feder, G. & Slade, R. (1984) The acquisition of information and the adoption of new technology. *American Journal of Agricultural Economics,* 66(August).

Feder, G., Just, R. & Zilberman, D. 1982. *Adoption of Agricultural Innovation in Developing Countries.* Washington DC, The World Bank.

Figueroa, A. 1986. *Productividad y educación en la agricultura campesina de América Latina* Lima, Inter-American Development Bank.

Figueroa, A. 1988. Productividad agrícola y crisis económica en el Perú. *Economía* PUCP, XI, (22, December).

Gallardo, J. 1994. Efectos del proceso de ajuste estructural sobre los determinantes de la productividad en la economía campesina. *Perú: El Problema Agrario en Debate. SEPIA V.* Lima, SEPIA.

Gomez , R. 1995. Exportación y relaciones contractuales en Perú: el caso del mango. *Las relaciones agroindustriales y la transformación de la agricultura.* Santiago de Chile, CEPAL.

Gonzales, E. (1996) *Inversión privada, crecimiento y ajuste en el Perú, 1950-1995.* Lima, IEP, Documento de Trabajo No. 1.

Guerra, J. 1986. Alternativas de inversion publica. *In* A. Figueroa & J. Portocarreo, eds. *Prioritazión y desarrollo del sector agrario en el Perú.* Lima, PUCP and Fundacion Frederich Ebert.

Hopkins, R. 1981. *Desarrollo desigual y crisis en la agricultura peruana 1944-1969.* Lima, IEP.

IICA (Instituto Interamericano de Cooperacion para la Agricultura) .1990. *El sector agropecuario peruano. situación y perspectiva para su reactivación.* Lima, IICA

INEI (Institucion Nacional de Estadistica e Informatica). 1995. Peru: series estatdisticas 1970-1994. Lima, INEI.

INEI. 1996. Los ciclos economicos en el Peru: 1950-1995. Lima, INEI, March.

INEI. 1997. Compendio estadistico economico-financiero, 1996-1997. Lima, INEI.

INEI. Various years. Peru: compendio estadistico" 1990-92, 1995-96. Lima, INEI.

Instituto Cuanto 1995. *Retrato de la familia peruana. niveles de vida,1994.*Lima: IC, UNICEF.

Johansen, S. 1988. Statistical analysis of cointegration vectors. *Journal of Economics Dynamics and Control,* 12(2/3).

Johansen, S. & Juselius, K. 1990. Maximum estimation and inference on cointegration with application to the demand for money. *Oxford Bulletin of Economics and Statistics,* 52.

Leon, J. 1994. Política de estabilización y crisis agraria. In Dancourt, Mayer & Monge, eds. *Perú: el problema agrario en debate. SEPIA V.* Lima.

MAG (Ministry of Agriculture). 1992. Primer compendio estadistico agrario, 1950-1991. Lima, MAG and Oficina Sectorial de Estadistica.

MAG. 1994. Compendio Estadístico Agrario 1993. Lima, MAG Oficina de Informacion Agraria.

MAG. Various years. *Estadistica Agraria Mensual*. Lima, MAG Oficina de Informacion Agraria, bulletins since 1970.

MAG. Various years. Reports of the Office of Agricultural Investment 1992-1996. Lima, MAG, mimeo.

Maletta, H. &. Foronda, J. 1980. La acumulacion del capital en la agricultura peruana. Lima, CIUP.

Marañon, B. 1991. Exportacion no tradicional: la agroindustria de alimentos. *Actualidad Económica,* 25(Mayo-Junio): 40-41

Marañon, B. 1994. Cambios sociales en las zonas de agroexportación en el Perú, costa norte. In Dancourt, Mayer & Monge, eds. *Perú: el problema agrario en debate. SEPIA V.* Lima.

Mendoza, W. 1992. Politicas macroeconomicas y agricultura, ¿Que es lo que sabemos? *Debate Agraria* Lima, 13 (Enero-Mayo).

Office of the President of the Republic. 1997. *FONCODES*. Note 24, Lima, July-September.

Olaechea, J. & San Miguel, H. 1993. *Agroexportación y modernización en la región Grau.* Piura, CIPCA.

Portocarrero, J., ed. 1987. *Los hogares rurales en el Perú. importancia y articulación con el desarrollo agrario.* Lima, Fundación Friedrich Ebert.

Portocarrero, F., Beltran, A. & Zimmerman, N. 1988. *Inversiones públicas en el Perú (1900-1968): una aproximación cuantitativa*. Lima, CIUP, Cuadernos de Investigación.

Reimers, H. 1992. Comparisons of tests for multivariate cointegration. *Statistical Papers,* 33.

Rodriguez, M. 1997. Jóvenes desplazados retornantes e institucionalidad comunera y la propiedad comunal, paper given at SEPIA VII, Huancayo.

SEPAR. 1992. *Crisis y cronología de la violencia política en la región central del Perú (1980-1991).* Huancayo, SEPAR.

SINIA (Sistema Nacional de Informacion Agraria). 1993. Resultado de la construccion de marcos muestrales en los valles e irrigaciones de los departamentos de la costa. Lima, MAG, Oficina de Informacion Agraria.

Superintendencia de Banca y Seguros. Various years from 1990. Memoria. Lima, Superintendencia de Banca y Seguros.

Torero, M. 1992. La adopción de la innovación tecnológica en la agricultura tradicional del Perú: la asociación geográfica como una alternativa para la difusión. In I. Degregori, J. Escobal & B. Marticorena, eds. *Perú: el problema agrario en debat SEPIA IV.* Lima, SEPIA.

Twomey, M. 1989. La crisis de la deuda y la agricultura latinoamericana. *Revista Economía* de la PUCP, Lima, 12(24, December).

Vasquez, A. 1995. *La agricultura peruana en el siglo XXI: retos y oportunidades*. Lima, MAG.

Velazco, J. & Beteta, E. 1993. La demanda de asistencia técnica en la agricultura peruana, mimeo.

Velazco, J. & Caballero, V. 1996. Impacto de las políticas de ajuste estructural en Bambamarca. Study commissioned by Ayuda en Acción and Comision de Asesoria Laboral del Peru (CEDAL), mimeo.

Velazco, J, Velazco,T. & Sulen, F. 1990 *Movilizaciones agrarias 1985-1989: un análisis económico.* Lima, PUCP -Departamento de Economía, Documento CISEPA No. 89.

Von Oppen, M., Njehia, B. & Tifijaimi, A. 1997. The impact of market access on agricultural productivity: lessons from India, Kenya and the Sudan. *Journal of International Development,* 9(1).

Webb, R. & Fernandez Baca, G. 1995. *Peru 95 en números, anuario estadístico*. Lima, Instituto Cuanto.

Webb, R. & Fernandez Baca, G. 1996. Primeros resultados. *Peru 1996.*

Zegarra, E. 1999. *El mercado de tierras rurales en el Perú.* Vol. I Analisis institucional. Santiago de Chile,

Section III
Country case studies

7. Agricultural policy, investment and productivity in sub-Saharan Africa: a comparison of commercial and smallholder sectors in Zimbabwe and South Africa

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This study examines the impact of agricultural policies and investment on productivity in Zimbabwe and South Africa, for which the most complete productivity-related data in sub-Saharan Africa are available. Of particular interest are comparisons of the effects of such policies and investments on commercial and smallholder agriculture. The commercial and smallholder sectors in the two countries exhibit potentially significant differences in resources, policy support, and market conditions and thus in the impacts of policy changes and investment on agricultural productivity. Existing research on commercial and smallholder agricultural productivity in Zimbabwe and South Africa is reviewed. Recognizing the extent to which historic policy measures influenced the structure of agriculture in the two countries today, the study also assesses the sensitivity of existing estimates of productivity to changes in investment, policy and assumptions about human capital.

7.1 Introduction

Zimbabwe and South Africa differ from most other African countries in the degree of past and present European involvement in their economies. Nevertheless they share a similar institutional heritage with many other African countries, particularly in eastern and southern Africa, in terms of the evolution of agricultural policy over the course of the twentieth century. This evolution has been characterized in much of eastern and southern Africa by an early bias towards large-scale commercial agriculture, with land, labour and capital markets structured accordingly. This was followed around the period of independence by subsequent policy redirection in support of the smallholder agricultural sector, followed more recently still by market liberalization and structural adjustment.

In seeking to understand the impact of these policy changes on the productivity of agriculture, Zimbabwe and South Africa are uniquely valuable as case studies in the extent to which sector-specific agricultural productivity-related data and research are available. This allows intersectoral comparisons of agricultural productivity based on differences in inputs, land quality and policy variables while controlling for factors such as climate, as well as identification of potentially interesting intersectoral spillover effects that may also be significant. Identifying the sources

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Table 7.1 Selected indicators of agricultural productivity

Indicator	Zimbabwe	South Africa	Sub-Saharan Africa	World
Fertilizer use (kg/arable ha, 1980)	61	87	16	86
Fertilizer use (kg/arable ha, 1995)	62	51	13	94
Tractors (per 1 000 ha cropland, 1993)	7	8	3	21
Ag output (percent of GDP, 1996)	14	5	24	na
Ag output growth (percent/yr, 1980-1990)	2.4	2.9	1.8	2.8
Ag output growth (percent/yr, 1990-1996)	4.5	1.4	2.1	1.7
Cereal yield (kg/ha, 1980)	1 359	2 117	1 100	2 230
Cereal yield (kg/ha, 1995)	1 163	1 918	1 041	2 561
Ag productivity (US$/ha, 1980)	34	45	53	na
Ag productivity (US$/ha, 1993)	41	49	68	236
Ag productivity (US$/worker, 1980)	294	2 361	458	na
Ag productivity (US$/worker, 1995)	266	2 870	392	na

Note: figures are three-year moving averages.
Source: World Bank (1998); tractors from WRI/UNEP/UNDP/WB (1998).

of smallholder agricultural productivity growth in Zimbabwe and South Africa may thus provide important insights into agricultural development strategies elsewhere in sub-Saharan Africa (SSA).

Recent trends in agricultural productivity in Zimbabwe and South Africa

Table 7.1 provides selected indicators of input use, output growth and agricultural productivity for Zimbabwe and South Africa in relation to the rest of SSA and the world. At 50 to 60 kilograms per arable hectare in 1995, fertilizer use in both countries is four to five times the level in the rest of SSA, but (with the exception of South Africa in 1980) remains 30 to 40 percent below world averages. A similar pattern is evident for use of tractors. Agricultural output grew at an average rate of 2.4 percent per year in Zimbabwe and 2.9 percent per year in South Africa in the 1980s, at roughly the same pace as world agricultural output growth, compared with 1.8 percent per year in the rest of SSA. Between 1990 and 1996, agricultural output growth slowed to 1.7 percent per year for the world as a whole, slowed to 1.4 percent per year in South Africa, accelerated to 2.1 percent per year in SSA and accelerated to 4.5 percent per year in Zimbabwe.

Changes in agricultural productivity depend on how rapidly agricultural output changes in comparison with changes in input levels. Partial indicators of agricultural productivity, such as yields per hectare or the value of output per worker are also reported in Table 7.1. For example, cereal yields fell from 1 359 kilograms per hectare to 1 163 kilograms per hectare in Zimbabwe between 1980 and 1995, a decrease of 1.0 percent per year. Over the same period, cereal yields in South Africa fell from 2 117 kilograms per hectare to 1 918 kilograms per hectare, a decrease of 0.7 percent per year. Meanwhile SSA-average cereal yields fell from 1 100 kilograms per hectare to 1 041 kilograms per hectare, and world-average cereal yields rose from 2 230 kilograms per hectare to 2 561 kilograms per hectare (an increase of 0.9 person annually).

Land productivity in agriculture, as measured by the value of output per hectare of arable land, grew in both countries and in SSA as a whole between 1980 and 1995. In Zimbabwe, agricultural land productivity grew from US$34 per hectare in 1980 to US$41 per hectare in 1995, an annual increase averaging 1.3 percent. Agricultural land productivity in South Africa grew from US$45 per hectare to US$49 per hectare over the same period, an average increase of 0.6 percent per year. Agricultural land productivity grew even more rapidly in SSA as a whole, starting from a higher base, from US$53 per hectare in 1980 to US$68 per hectare in 1995, an average increase of 1.7 percent per year. Even at US$68 per hectare, however, SSA land productivity levels remain less than one-third world-average levels.

Labour productivity is measured as the value of agricultural output per agricultural worker. Here patterns differ from those for land productivity. While agricultural labour productivity rose at an annual average rate of 1.3 percent in South Africa between 1980 and 1995, from US$2 361 per worker to US$2 870 per worker, it fell in Zimbabwe and in SSA as a whole. Labour productivity fell in Zimbabwe at an average rate of 0.7 percent per year, from US$294 per worker to US$266 per worker, and in SSA as a whole at an average rate of 1.0 percent per year, from US$458 per worker to US$392 per worker.

These mixed trends in input use, output growth and agricultural productivity raise questions about the performance of agriculture in Zimbabwe and South Africa. The remainder of this paper explores these trends in productivity and the factors that underlie them, with a focus on the role of investment in improving agricultural productivity. Special attention is given to investment in human capital and its impact on productivity.

7.2 The historical context

Deininger and Binswanger (1995) argue that in Zimbabwe and South Africa, as in Kenya, farming on large operational holdings was made economically feasible in large part due to policy distortions designed to favour large-scale European farmers over African smallholders. Otherwise, they argue, given the relatively low capital intensity and high labour intensity of both large-scale and small-scale agricultural production in Africa, supervisory costs for labour would become an important factor favouring smallholders.

Promotion of European commercial farmers

In both Zimbabwe and South Africa, a series of interventions favoured European farmers over African smallholders in markets for outputs as well as for land, labour, credit and other inputs (Kassier and Groenewald, 1990; Deininger and Binswanger, 1995). In Zimbabwe, the Land Apportionment Act of 1930 limited African land purchases to selected marginal areas, and government assistance was provided to white farmers for virtually all crop and livestock products through subsidies and state monopolies. In South Africa, the Native Lands Act of 1913 and other aspects of a deliberate apartheid policy sharply restricted African access to land, in order to reduce competition with white farmers in labour and output markets and increase the supply of African labour to the expanding mining industry. Government transfers to white farmers for marketing assistance alone averaged over 30 million South African Rand annually between 1948 and 1966 (Deininger and Binswanger, 1995).

These policies contributed to the emergence of the dualistic structure of landholding and production that characterizes agriculture in Zimbabwe and South Africa today. In Zimbabwe, one million communal farm households occupy about half of the arable cropland, while the other half is farmed by 4 500 large-scale commercial farmers, most of whom are white (Atkins and Thirtle, 1995). Compounding this, roughly three-quarters of communal lands are located in agro-ecological regions averaging 500 millimetres or less of annual rainfall (Mudimu, 1990). In South Africa, about 70 000 commercial farms occupy approximately 85 million hectares, while a subsistence-oriented sector, with problems characteristic of much of sub-Saharan Africa, occupies approximately 15 million hectares (van Zyl, Vink and Fenyes, 1987; van Zyl and Groenewald, 1988). Farmland per caput in the homelands established by the Native Lands Act of 1913 averaged less than three hectares in 1990, compared with over 18 hectares in the rest of South Africa (Kassier and Groenewald, 1990).

In addition, policy through much of the twentieth century favoured investment in European commercial agriculture over smallholder production. Research on hybrid maize began in Zimbabwe in 1932, and by 1949 Zimbabwe had become the second country in the world (after the United States) to market hybrid maize seed (Eicher and Rukuni, 1990). Zimbabwe's "first Green Revolution" (Eicher, 1995) was launched in 1960, spearheaded by and for white commercial farmers, and based on large public and modest private investments in new technology, physical and biological capital (e.g. rural infrastructure and new seed varieties), human capital (e.g. education) and farmer support institutions.

While improving yields on white commercial farms, these policies resulted in a gradual decline in the productivity of African smallholder agriculture. In Zimbabwe's communal areas, per caput grain production (a crude measure of labour productivity) declined from about 300 kilograms to about 200 kilograms between 1925 and 1980 (Jayne and Jones, 1997).

In South Africa, tax concessions on capital improvements and subsidies for white commercial agriculture in general led to steady investment in machinery in the decades following World War II (van Zyl, Vink and Fenyes, 1987). Until about 1970, mechanization was focused on the substitution of machinery for draughtt animal power in cultivation, while harvesting operations remained labour-intensive. With yields increasing, this brought about increased demand for labour. After 1970, with the introduction of mechanized harvesting, capital became a substitute for labour, leading to reductions in farm employment in major maize-producing areas. Subsequent increases in agricultural employment have been associated with the disappearance of interest rate subsidies and the phasing out of tax concessions for machinery purchases (Kassier and Groenewald, 1990; Thirtle, Townsend and van Zyl, 1998).

Policy reorientation toward smallholders

Following independence in 1980, government policy in Zimbabwe sought to balance equity and growth-oriented objectives through provision of public services and infrastructure, including substantially expanded credit and market infrastructure for smallholders, to encourage rapid increases in smallholder agricultural productivity (Atkins and Thirtle, 1995; Jayne *et al.*, 1994). The new government in Zimbabwe also embarked on a programme of land resettlement that by 1990 had succeeded in resettling 52 000 families, most of them from the communal areas, on 2.5 million hectares purchased from European commercial farmers (Eicher and Rukuni, 1990). Ongoing plans call for the acquisition and resettlement of an additional 5 million hectares.

Zimbabwe's "second Green Revolution" focused on smallholders following independence in 1980 (Eicher, 1995). Underlying this second revolution were the inheritance of a productive public agricultural research system, a quadrupling in the number of government-provided loans to smallholders (Eicher and Rukuni, 1990), a sharp increase in guaranteed producer prices and a 30-fold increase in the number of Government Marketing Board (GMB) grain-buying depots and collection points. Together, these factors resulted in the rapid adoption of hybrid maize varieties and fertilizer by smallholders. Sales of hybrid maize seed and fertilizer to the small holder sector increased nearly five-fold between 1979 and 1985 (Rohrbach, 1990). As a result, smallholder maize production doubled from 738 000 tonnes in 1980 to 1.3 million tonnes in 1986 (Eicher, 1995). In the decade following independence, maize yields rose at an average rate of 6.7 percent per year, while cotton area and yields increased by 25 percent and 1.3 percent per year, respectively (Deininger and Binswanger, 1995).

Despite policy changes, yield differences between commercial and communal areas continue to reflect marked differences in access to input and output markets, land quality and climate. For example, maize yields in Zimbabwe's commercial sector are 50 percent to 200 percent higher than maize yields on comparable land in the smallholder sector (Deininger and Binswanger, 1995). Even within the smallholder sector, wide variations in behaviour are apparent. The 25 percent of communal lands in the most favourable agro-ecological zones, with 20 percent of the total smallholder population, accounted for 68 percent of smallholder maize production, 80 percent of smallholder maize sales and 91 percent of smallholder fertilizer use in the late 1980s (Rohrbach, 1990).

In South Africa, the reorientation of policy toward smallholders has included the scrapping of the Land Acts in 1991, the application of labour legislation to farm workers and the establishment of the Farmer Support Programme (FSP) (van Zyl, Fenyes and Vink, 1992). The FSP is designed to ensure that black smallholders in the homelands are provided with improved access to input markets, output markets, research and extension services, training and educational opportunities, physical infrastructure and secure tenure. The hope is that these services will create the conditions for the commercialization of the smallholder agricultural sector.

Market liberalization and structural adjustment

Across eastern and southern Africa, government-led provision of services to smallholders has proven to be extremely expensive and ultimately unsustainable. Jayne and Jones (1997) argue that production gains in Zimbabwe and South Africa have been achieved only at a cost greater than the value of the increased output. By the mid-1980s, the costs of these services, combined with vast accumulating surpluses of maize, forced a reappraisal of government policies in Zimbabwe (Eicher, 1995). Government-provided credit to smallholders was scaled back, as were marketing subsidies and grain-buying depots in communal areas (Atkins and Thirtle, 1995). In 1990, the government launched a programme of structural adjustment with the backing of the International Monetary Fund and the World Bank, which deregulated markets and reduced public expenditures (Marquette, 1997). Implementation of this programme coincided with an unusually severe drought across southern Africa in 1991-1992, causing declines in agricultural production, employment and wages, as well as in other indicators of social welfare that had improved dramatically in the 1980s. In spite of increased population pressure on smallholder lands, total cropped area in Zimbabwe has decreased slightly since the mid-1980s (Jayne *et al.*, 1994), and fertilizer purchases by smallholders have stagnated since 1993 (Jayne and Jones, 1997).

Throughout eastern and southern Africa state maize marketing agencies continue to play a significant role in most countries despite regulatory reforms in recent years. In South Africa, maize price controls and trade restrictions were lifted in 1995, following similar measures in Zimbabwe in 1993 (Jayne and Jones, 1997). However, the effects of these measures are difficult to assess because of the confounding affects of recent extreme weather events, because these measures may not yet have been fully implemented, and because data on factor productivity remain incomplete. Nonetheless, both Zimbabwe and South Africa, traditionally reliable producers of grain surpluses, have seen steady declines in their net exports in recent years (Jayne and Jones, 1997).

Despite concerns that structural adjustment might result in maize price increases detrimental to the food security of urban and rural consumers, Jayne *et al.* (1996) report that some adjustment measures have improved household food security by reducing costs. Specifically, easing of restrictions on private grain transportation, marketing and processing since 1993 have significantly reduced the cost of maize meal, a staple in the Zimbabwean diet. The proportion

Table 7.2 Selected indicators of human capital

Indicator	Zimbabwe	South Africa	Sub-Saharan Africa	World
Population (millions, 1996)	11	38	596	5 754
Population growth (percent/year, 1980-1996)	3.0	2.0	2.8	1.6
Population (millions, 2010)	14	46	844	6 788
GNP per caput (US$, 1996)	610	3 520	490	5 130
GNP per cap growth (percent, 1965-1996)	0.4	0.2	-0.2	1.2
Life expectancy (m,f; years, 1996)	55, 57	62, 68	51, 54	65, 69
Adult literacy (m,f; percent, 1995)	90, 80	82, 82	66, 47	79, 62
Percent labour force in ag (m,f; 1994)	58, 81	16, 10	65, 75	48, 52
Percent population < US$1 per day (1990s)	41	24	na	na

Source: World Bank (1998).

of maize meal acquired through informal channels has risen from eight percent to 50 percent, at cost savings of 30 to 40 percent, representing savings equivalent to about ten percent of income among the poorest urban consumers. Rubey and Lupi (1997) estimate that for all but the highest income group, easing of these restrictions has more than offset the welfare losses due to removal of consumer subsidies.

Current resource conditions

Agricultural performance in Zimbabwe and South Africa is influenced by their resource base as well as by their policy histories. Table 7.2 presents selected indicators of human resources in the two countries. Zimbabwe's population of 11 million (1996) is growing at a rate of three percent per year, and is projected to reach 14 million by the year 2010. South Africa's 1996 population of 38 million is growing more slowly, at two percent, and is expected to reach 46 million by 2010. The two countries together currently represent about eight percent of sub-Saharan Africa's population.

GNP per caput was nearly six times as great in South Africa in 1996 as it was in Zimbabwe, and more than seven times the average for sub-Saharan Africa as a whole, although these figures mask sharp distributional differences within each country. At 55 years and 57 years for men and women, respectively, life expectancies in Zimbabwe were slightly higher than for sub-Saharan Africa as a whole in 1996, while South Africa's life expectancies were closer to world averages, at 62 and 68 years respectively. Conversely, adult literacy rates were 90 percent and 80 percent for men and women, respectively, in Zimbabwe in 1995, and 82 percent for both men and women in South Africa, higher than both world and sub-Saharan African averages.

In Zimbabwe, as in most of sub-Saharan Africa, most women who are active in the labour force (three-quarters to four-fifths) are employed in agriculture, while in South Africa the figure is much lower, at ten percent. A similar pattern holds true for men: 58 percent in Zimbabwe, 65 percent in sub-Saharan Africa as a whole and 16 percent in South Africa. The corresponding worldwide averages are about one-half for both men and women. As a final indicator of human resources, about 41 percent of Zimbabwe's population are estimated to live on less than US$1 per day, as is true for about 24 percent of South Africa's population. Comparable figures are not available at the regional and global levels.

Table 7.3 Selected indicators of natural capital

Indicator	Zimbabwe	South Africa	Sub-Saharan Africa	World
Land area (1 000 km^2, 1995)	387	1 221	23 628	130 129
Cropland (percent land area, 1980)	7	11	6	11
Cropland (percent land area, 1995)	8	13	7	11
Pasture (percent land area, 1995)	44	67	34	26
Forest (percent land area, 1995)	22	7	17	25
Protected (percent land area, 1994)	8	6	6	7
Percent cropland irrigated (1995)	5	8	4	18
Ag land per worker (ha, 1980)	8.4	50.3	7.9	3.9
Ag land per worker (ha, 1993)	6.0	51.0	6.0	3.8
Freshwater (m^3 per caput, 1996)	1 254	1 190	7 821	7 342

Source: World Bank (1998).

Selected indicators of agriculture-related natural resources are presented in Table 7.3. Both Zimbabwe and South Africa had proportionately more land in cropland (eight percent and 13 percent, respectively) and in pasture (44 percent and 67 percent, respectively) than did sub-Saharan Africa as a whole. Five percent of Zimbabwe's cropland was irrigated in 1995, compared with eight percent in South Africa and 4 percent for sub-Saharan Africa as a whole. In terms of overall freshwater availability per caput, both Zimbabwe and South Africa are relatively dry, each with about 15 percent the freshwater available at the average regional and global levels. By the year 2050, Zimbabwe and South Africa are projected to have about 860 and 560 cubic metres of freshwater available per caput, respectively. One thousand cubic metres is considered the threshold below which water availability becomes a severe constraint on socio-economic development and environmental quality (Meinzen-Dick and Rosegrant, 1997).

Lal (1998) and Tagwira (1992) estimate that 15 percent of the land area in Zimbabwe is very severely eroded, 13 percent is severely eroded, 19 percent is moderately eroded and 53 percent is not eroded. Soil erosion averages 25 tonnes per hectare per year under traditional farming practices, 37 tonnes per hectare per year on commercial farms under continuous cotton and 17 tonnes per hectare per year on commercial farms under continuous maize. Erosion is estimated to have reduced maize yields by two to five percent per tonne of soil lost (Lal, 1998; Hudson and Jackson, 1959).

7.3 Existing research on agricultural productivity in Zimbabwe and South Africa

Zimbabwe's communal sector

Jayne *et al.* (1994) examine changes in total factor productivity in Zimbabwe's smallholder agricultural sector over the period 1975-1990. They use a profit function approach to estimating total factor productivity (TFP), which facilitates measurement of policy effects on prices and productivity. They find that smallholders are responsive to maize price incentives, and thus to policies that influence maize consumption. For example, a subsidy that reduces the consumer price of maize by ten percent is estimated to stimulate subsequent year's crop input use by 1.6 percent and maize output by 5.6 percent.

Jayne *et al.* (1994) found the effects of research and development (R&D) on TFP in the smallholder sector to be insignificant. The use of maize hybrids increased from 29 percent of smallholder maize area in 1979 to virtually 100 percent by 1985. They note, however, that these hybrids had been available for a full decade previously, and attribute their eventual near-universal adoption to the post-independence expansion of credit and market infrastructure for smallholders in the early and mid-1980s. They conclude that the full impact of R&D may not be realized without complementary investment in the physical and institutional infrastructure necessary for input and output markets to function efficiently. By contrast, Thirtle *et al.* (1993) estimated that the rate of return to R&D in Zimbabwe's commercial sector, characterized by relatively well-functioning markets for inputs, outputs and credit, was between 40 percent and 60 percent.

While Jayne *et al.* (1994) integrated R&D directly into their profit function, Atkins and Thirtle (1995) use a modified two-stage methodology to analyse the same data in order to measure and explain growth in TFP in Zimbabwe's communal sector over the period 1975-1990. First, they derive a measure of TFP as the ratio of an aggregate output to an index of aggregate inputs. Changes in TFP are then explained in terms of changes in R&D, extension and farmer education. Atkins and Thirtle estimate that TFP grew at an annual average rate of 1.7 percent over the entire period, but find that this average conceals significant variation. Specifically, they estimate that TFP declined at an average rate of 0.8 percent annually between 1975 and 1980, increased at an average rate of 8.1 percent annually between 1980 and its peak in 1985, and then decreased at an average rate of 2.7 percent annually between 1985 and 1990.

Atkins and Thirtle find that labour and land together account for the bulk of input costs. Growth in population combined with the purchase of commercial sector farmland for resettlement contributed to growth in the use of both these inputs by the communal sector throughout the period, although the pace of resettlement has slowed since 1985. The use of hybrid seeds, fertilizer and chemical inputs grew at an average rate of 22.6 percent per year between 1980 and 1985, contributing to partial productivity growth rates for land and labour of 9.2 percent and 9.5 percent per year over the period, exceeding the growth in TFP. While the value of own consumption of agricultural output increased at an average annual rate of only 1.2 percent between 1975 and 1990, the value of sales by the communal sector (primarily maize and cotton) increased at an average annual rate of 26.4 percent over the same period. Between 1985 and 1990, sales declined at an annual average rate of one percent. However, while the government invested in infrastructure, credit and technology for the communal sector between 1980 and 1985, sales grew at an average rate of 33.1 percent per year.

In the second stage of their analysis, Atkins and Thirtle estimate how TFP is affected by changes in R&D, extension, education and other policy indicators (reflecting the number of government input-supply and output-purchasing depots and the provision of credit to the communal sector), while controlling for weather. They found that weather and the number of depots explain 80 percent of the variation in TFP between 1979 and 1990. Dalton, Masters and Foster (1997) also find a close association between production costs and access to markets in Zimbabwe's smallholder sector, emphasizing the importance of rural infrastructure in influencing production decisions.

While R&D was found to be insignificant in explaining changes in TFP, Atkins and Thirtle argue that hybrid maize still played a crucial role in the growth of TFP in Zimbabwe's communal sector. As Eicher (1995) points out, however, virtually the entire commercial sector maize crop was already planted to hybrid varieties well before independence, so communal sector farmers were able to draw readily on this technology.

Zimbabwe's commercial sector

Thirtle *et al.* (1993) use both a two-stage decomposition approach and an integrated production function approach to analyse productivity in Zimbabwe's commercial agricultural sector for the period 1970-1990. They find that the growth in aggregate output slowed to 2.7 percent annually in the 1980s, from 4.4 percent in the 1970s, while aggregate input use actually declined in the 1980s by 1.2 percent annually after increasing in the 1970s by 0.5 percent annually. The combined effect of these two trends was that total factor productivity in Zimbabwe's commercial sector was relatively stable before and after independence, growing at an average annual rate of 3.9 percent in the 1970s and 4.0 percent in the 1980s. The authors find that investment in R&D and extension explain over 90 percent of the variation in TFP over the period 1970-1990, and had an internal rate of return of 40 to 60 percent.

South Africa's commercial sector

Thirtle, Sartorius von Bach and van Zyl (1993) studied TFP growth in South Africa's commercial sector over the period 1947-1991, using the Tornqvist-Theil approximation of the Divisia index. They find that the output index rose at an average annual rate of three percent over the period, the input index grew at an average annual rate of 1.8 percent and TFP grew at an average annual rate of 1.3 percent. These overall averages mask a 0.9 percent annual decline in the input index after 1979 (following annual growth of 2.5 percent for 1947-1979), and a subsequent acceleration in TFP growth since 1981 to 2.9 percent per year. Labour and land productivity each rose by more than three percent annually between 1947 and 1991, due to the increased use of intermediate inputs (such as fertilizer and high yield varieties [HYVs]) and capital inputs (such as machinery) relative to labour and land. Mechanization in particular was supported by cheap credit and tax concessions during the 1970s. When these concessions declined in the early 1980s, labour became cheaper relative to capital, and labour use increased for several years before falling again later in the decade.

Thirtle, Sartorius von Bach and van Zyl (1993) then seek to explain observed changes in TFP in terms of changes in R&D, extension services and farmer education. They also add variables for international technology transfer (based on lagged United States TFP) and for weather. Coefficients on R&D, extension and education were positive and significant, although very sensitive to changes in specification.

Khatri, Thirtle and van Zyl (1996) revisit the results found by Thirtle, Sartorius von Bach and van Zyl (1993), using a profit function approach directly incorporating the conditioning effects of local public sector agricultural research and international research spillovers. They point out that South African agriculture remains subject to widespread policy distortions that affect its structure and performance. For example, subsidized farm credit resulted in negative real interest rates in the 1970s and into the early 1980s, and resulted in considerable over-capitalization.

Khatri, Thirtle and van Zyl find that public research expenditures and the international stock of knowledge (in the form of agriculture-related chemical and mechanical patents registered in the United States) are significantly and positively related to productivity growth in South Africa's commercial agricultural sector, particularly with respect to field crops. The authors estimate that the rate of return to public-sector R&D is 44 percent, but argue that these returns would be much smaller, or even negative, if returns to R&D could be adjusted for the full social costs of high unemployment and poverty in rural areas. Extension is found to have a significant but very small effect on productivity, while farmer education is found to have a significant and negative effect. The authors suggest this may be due to over-mechanization and over-application of fertilizer on the part of better-educated farmers, driven by emphasis on maximization of production rather than profits. The authors conclude that policy and R&D together have distorted incentives that would otherwise lead to profit maximization reflective of South Africa's relatively abundant labour and relatively scarce capital.

7.4 Data

Thirtle, Sartorius von Bach and van Zyl (1993) did a careful study for South African commercial agriculture that is the first attempt to measure South African TFP at the national aggregate level, and this paper draws extensively on this work. For comparison, Thirtle *et al.* (1993) develop an innovative set of comparable computations for the commercial and communal sectors in Zimbabwe. Atkins and Thirtle (1995) note that a lack of adequate time series data has so far prevented the measurement of TFP elsewhere in sub-Saharan African agriculture. The comparisons in section 7.5 use data from published estimates of TFP for South Africa's commercial agricultural sector and for Zimbabwe's commercial and communal agricultural sectors (Thirtle, Sartorius von Bach and van Zyl, 1993; Thirtle *et al.,* 1993; Atkins and Thirtle, 1995; Khatri, Thirtle and van Zyl, 1996; Thirtle, Townsend and van Zyl, 1998). The TFP indices calculated by these authors are described below. Included in the discussion are the strengths and weaknesses of the available statistical sources, and accommodations that were made for shortcomings. The result is three comparable data sets that address the conceptual problems involved in transforming aggregate agricultural accounting data into production data in a way that is consistent with its theoretical basis; the Tornqvist-Theil approximation of a Divisia index.

South Africa's commercial sector

Outputs

The numerator of a TFP index is aggregate agricultural output. The output shares are calculated using the currently priced series for the three main output categories, namely crops, horticulture and animals. These were adjusted for subsidies to give the prices actually faced by farmers. Laspeyres indices are calculated for the value of crops, horticultural products and animal products, using crop-years[2]. The year-on-year ratios of these indices are used to form the Tornqvist-Theil index.

Inputs

The denominator of the TFP index is an index of inputs used in agricultural production. This index has two components, each weighted by cost shares, and again the year-on-year ratios of these indices are used to form the Tornqvist-Theil index. There are two primary inputs, labour and land. In South Africa, data are available on the number of farm employees and domestic servants on farms, differentiating between males and females and between blacks and whites. For the physical units of labour, it was necessary to estimate the number of domestic servants so that they could be subtracted from the total farm labour force, and to estimate the proportion of a full- labour unit that a part-time employee represents (Thirtle, Sartorius von Bach and van Zyl, 1993). The index is not quality-adjusted for sex, wage or education.

The land index used by Thirtle *et al.* (1993) also fails to account for quality differences. Although van Schalkwyk and Groenewald (1992) have constructed a land quality index for South Africa, it provides only one observation for each country. Therefore, the index of Thirtle *et al.* tends to under-represent land when cultivated area is expanded on to poorer lands. However, some features of land quality are captured in the data. For example, land quality is related closely to the buildings and land improvements series included in the capital items below. The costs of irrigation are included in the intermediate inputs index. The share weights for land are

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[2] A crop-year is the period during which a crop actually grows even if that period happens to include more than one calendar year, as it often does in the Southern Hemisphere.

calculated from estimates of the values of land rent and the percentage of the area rented. Thus it was possible to impute a rental value to the entire area of land to get a measure of land value.

Intermediate inputs, as they are collected for the national accounts, are packing material, fuel, fertilizer, feed, dips and sprays and other inputs. The values of all inputs were deflated with the appropriate price indices, also from national accounts, in order to get the input series. As with the outputs, subsidies on fertilizer, feed and transport were used to adjust the value figures in order to reflect the actual prices to farmers. *Farm-produced* intermediate inputs will have used up primary inputs in their creation and allowance was made for this, so that the off-farm and on-farm items are treated consistently.

The treatment of capital items in the national accounts raises the same on-farm or off-farm issue and adds to it a stock-flow problem. It is the flow of services from the capital stock that should enter as inputs in the denominator of TFP, along with the other flow variables. The most obvious cases are items such as machinery and vehicles, where the purchase price is much larger than the annual value of service flows. The aggregate agricultural statistics provide sufficient information for the service flow emanating from these capital stocks to be measured as the sum of running costs, interest and depreciation.

The three capital items included are land and fixed improvements, machinery and equipment and animal capital stocks. The values of these capital items were used to calculate shares. The shares were then converted into interest and depreciation flows that were deflated using the appropriate price indices. The interest components of the service flows on all three items were fixed at the low rate of two percent per year to reflect the considerable credit subsidies that were available to commercial farmers over most of the period[3]. The depreciation series mostly deflate machinery at ten percent per annum and fixed improvements on land at two percent per year. The running cost elements obviously differ for the different categories. The appropriate charges that were included in the land improvement category are maintenance and repairs to fencing and buildings. For the animal capital stock, the situation was slightly different. An interest element was calculated on the value of the herds. Depreciation is included in the sense that the animals are depreciated 100 percent in the year of slaughter and feed represents a large element of running costs. Rather than keeping feed separate it was included in the animal capital series to prevent this from turning negative in bad years when large numbers of animals were lost. This was done because it is necessary for each of the individual series to be positive, so that they could be transformed into logarithms.

Zimbabwe's commercial and communal sectors

Having attained independence over a decade before South Africa with the Lancaster House agreement in 1980, the new government's agricultural policy in Zimbabwe was based on an important policy document "Growth with Equity" (Republic of Zimbabwe, 1981). One by-product of this policy was that communal agriculture's contribution to the national income accounts appears in a Central Statistical Office publication (CSO, annual), which is available from 1975 onwards. Available from this source is a comprehensive list of outputs and intermediate inputs, not including land and labour, in current value terms that are used to calculate value added in communal agriculture.

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3 An interesting element is included to reflect the opportunity cost of holding farm capital, and this has led observers such as Paul and Abey (1984) to recommend incorporation of the *real* after-tax return on a safe asset. Such a series would include negative values and the choice of real or nominal rates affects the capital input series considerably during inflationary periods like the 1970s. These authors followed USDA (1980) and used an arbitrary fixed rate. This appears to be the safest course, until more work has been done to support a more elaborate treatment of this difficult issue.

The problem with measuring the productivity of smallholder agriculture in Zimbabwe, as in most of the rest of sub-Saharan Africa, is that land markets are generally not free and active in the communal areas. In addition, there is only a small amount of hired labour, and the wage that is paid is often a poor indication of the returns to widely used family labour (Atkins and Thirtle, 1995). In Kenya, for example, Carter and Wiebe (1990) found that the marginal product of labour applied on small farms was only a fraction of the market wage for labour, indicating significant imperfections in the market for labour. Thus, price information is lacking in Zimbabwe for the two basic factors of production that together account for the major part of the cost of inputs. Thirtle *et al.* (1993) used information on the price of land purchased by the government for resettlement schemes and the commercial wage as proxies in order to calculate weights for land and labour.

This approach is a reasonable one for the commercial sector of Zimbabwe, but when input prices vary as widely as they do in the communal sector, input costs need to be compared with the value of output for an accurate measure of TFP (Atkins and Thirtle, 1995). When this is done, it becomes apparent that the value of most communal land is well below the price paid by the government for resettlement land purchased from commercial farmers, and that the return to family labour in the communal sector is far below the commercial wage rate. Rather than imposing prices that are too high for the two main inputs in order to obtain weights for aggregation, the value of the intermediate inputs was subtracted from the value of output. The resulting residual, which could be considered value added, was divided between land and labour using share weights calculated from extensive gross margin calculations from University of Zimbabwe/Michigan State University (1992).

The effect of this new assumption (Atkins and Thirtle, 1995) is that all profits are attributed to labour and land inputs, rather than allowing a "return to managerial ability" to remain as part of the TFP index for Zimbabwe as it does for South Africa. TFP estimates for both South Africa and Zimbabwe, irrespective of this last assumption, are both Tornqvist-Theil approximations of Divisia TFP indices, and are therefore comparable. Given the degree of historic distortion in input markets in the communal and commercial sectors of these two countries, the sensitivity analysis in the following section explores the impact of assumptions about human capital on estimated TFP.

7.5 Investment in human capital, policy and TFP

The studies analysed in section 7.3 provide a number of insights into the relationship between investment and agricultural productivity in Zimbabwe and South Africa. In this section the data described in the previous section are drawn on to look more closely at trends in total factor productivity in the three sectors to better understand how those trends have been influenced by patterns of investment in human capital and by government policies. The meta-analysis conducted here focuses on the labour component, distorted as it was by deliberate policy interventions over the course of the twentieth century.

Comparable TFP calculations for South Africa's commercial agricultural sector and for Zimbabwe's commercial and communal agricultural sectors are illustrated in Figures 7.1, 7.2 and 7.3. Moderate fluctuations and a rising trend since the mid-1960s characterize TFP in South Africa's commercial agricultural sector (Figure 7.1). Investment in R&D and extension services played a positive and significant role in explaining this trend (Thirtle, Sartorius von Bach and van Zyl, 1993; Khatri, Thirtle and van Zyl, 1996). Results for investment in education were mixed. During the 1970s, policy-generated market distortions in the form of subsidies led to over-investment in capital equipment by farmers. Subsequent reduction in these subsidies contributed to the observed acceleration in TFP growth during the 1980s.

Figure 7.1
TFP in South Africa's Commercial Agricultural Sector

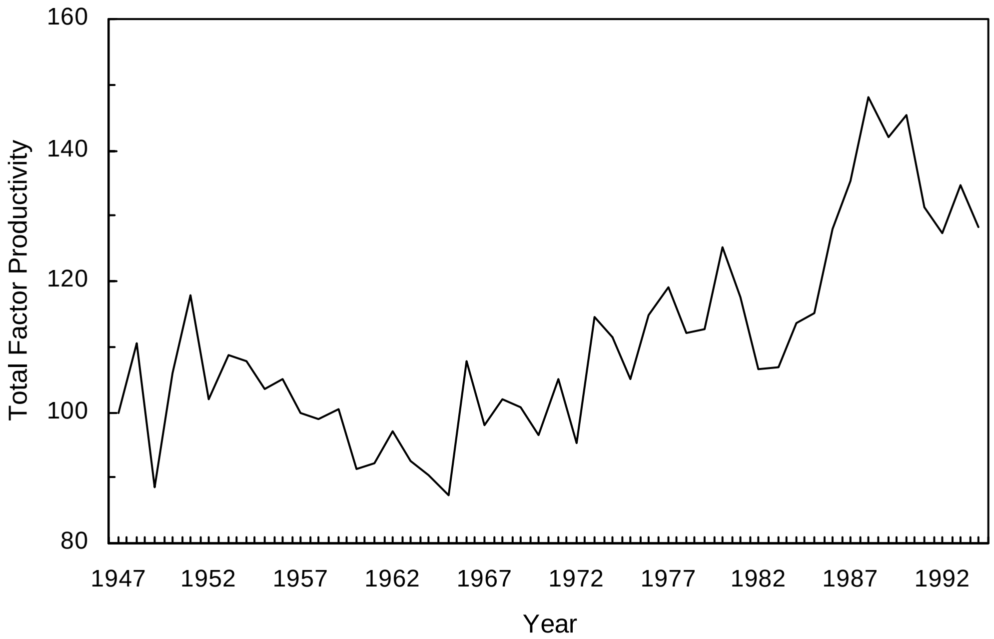
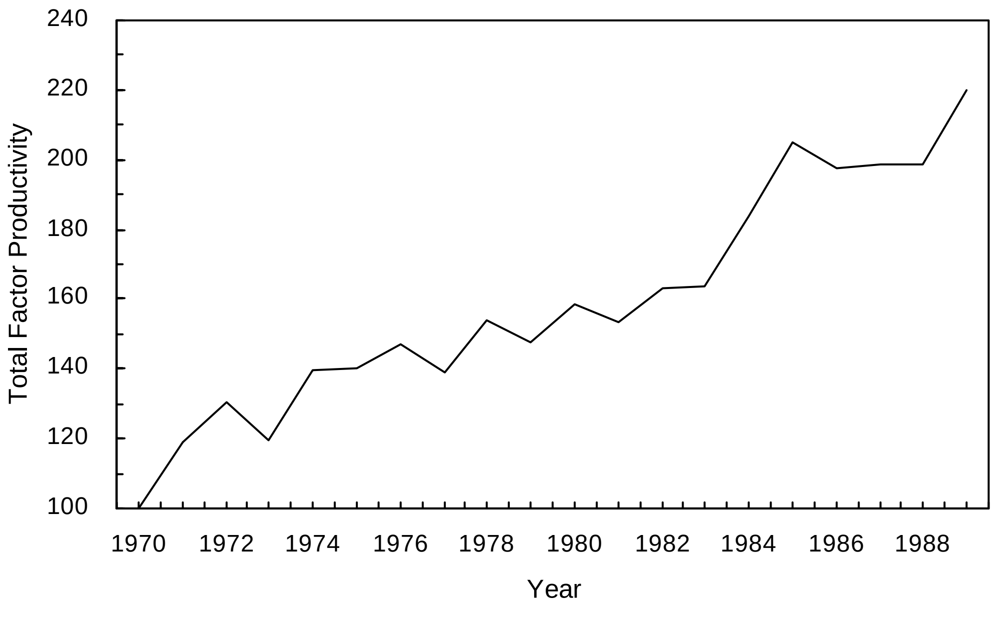


Figure 7.2
TFP in Zimbabwe's Commercial Agricultural Sector



TFP in Zimbabwe's commercial agricultural sector has also been characterized by a rising trend since 1970, but has fluctuated considerably less than South Africa's commercial agricultural sector (figure 7.2). As in the South African case, investment in R&D and extension services explained most of the growth in TFP (Thirtle *et al.*, 1993). While this sector was affected by the

Figure 7.3
TFP in Zimbabwe's Communal Agricultural Sector

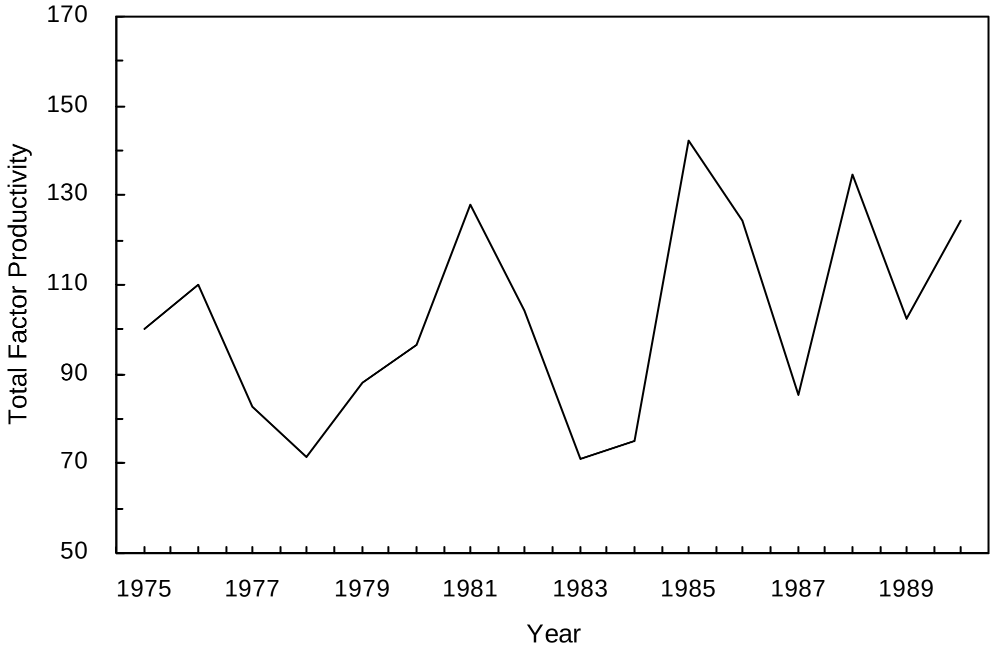
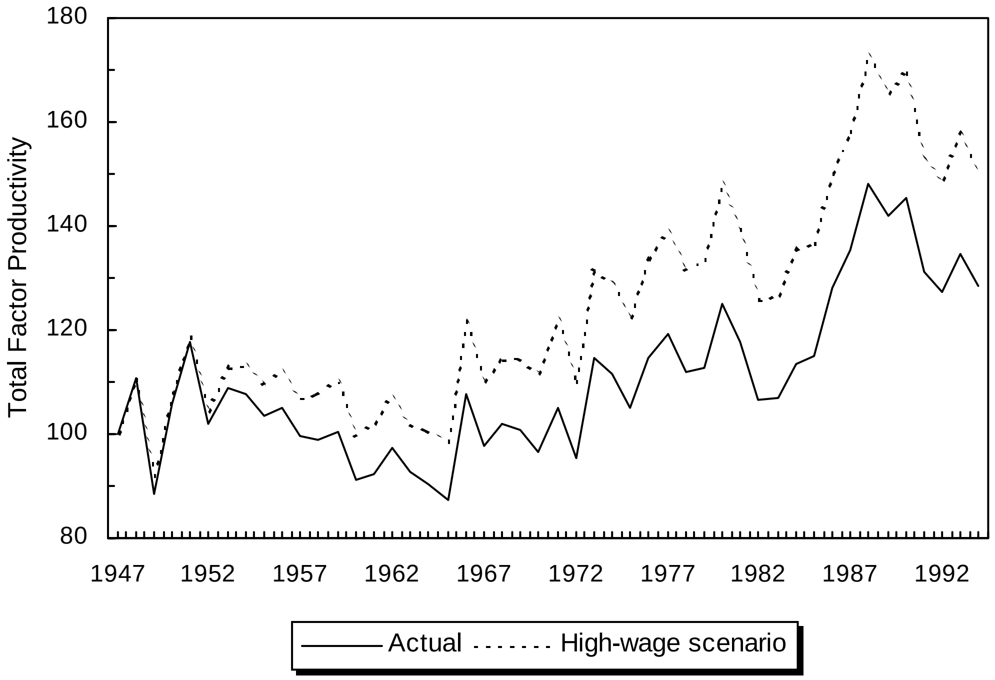


Figure 7.4
TFP in South Africa's Commercial Agricultural Sector



changes in policy favouring the communal sector brought about in the 1980s by the newly independent government, these changes produced similar drops in both input use and output in the commercial sector. As a result, TFP itself was largely unaffected.

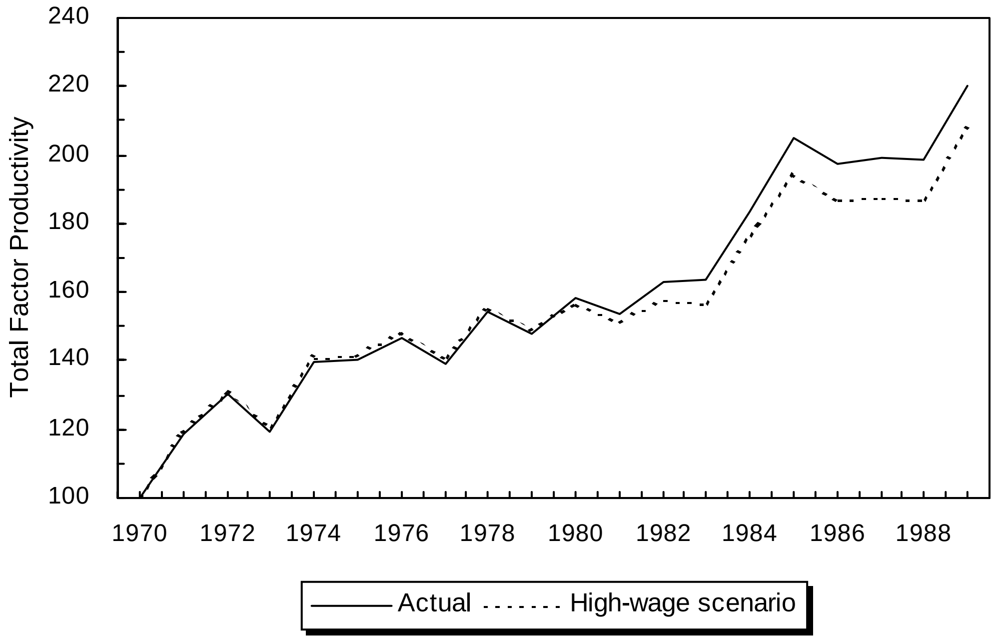
TFP in Zimbabwe's communal agricultural sector was also characterized by a rising trend, but this growth trend was slower than in either of the two commercial sectors considered. It was also much more volatile, varying by as much as 100 percent from year to year. In contrast to findings with regard to the role of R&D in the two commercial sectors, Jayne *et al.* (1994) and Atkins and Thirtle (1995) find that investment in R&D was not significant in explaining changes in TFP in Zimbabwe's communal sector. It is important to recall that communal sector farmers in Zimbabwe were able to draw on a readily available stock of hybrid maize varieties that had already been nearly universally adopted by Zimbabwe's commercial farmers. Much more important than additional R&D, then, was the role of investment in infrastructure. Specifically, improvement in access to markets, including government-supported input-supply and output-procurement depots in the 1980s, were found to be very important by Jayne *et al.* (1994), Atkins and Thirtle (1995) and Dalton, Masters and Foster (1997).

The analysis involves testing the sensitivity of TFP to different assumptions about the quality of labour, particularly in light of the low wages earned by black farm employees. As an indicator of the contribution of these employees to agricultural productivity, one can ask what agricultural productivity would have been if these employees had not had very low reservation wages and had been able to command a higher wage. Investments in human capital through the rural education system, particularly in South Africa, may have had significant impacts on agricultural productivity through their effects on the quality of labour available from farm workers. This in turn could have allowed workers to command higher wages. Thus, adjusting these wage figures gives an informative counter-factual example of labour costs that can then be used to generate a new estimate of TFP.

In the mining sector, non-blacks earned more than four times as much as blacks. In the agricultural sector black regular-agricultural employees earned less than a quarter the wages paid to black mining employees, and black casual-agricultural employees earned even less. These figures are not strictly comparable, however, as agricultural workers generally received a greater share of their total compensation in forms other than financial remuneration, including clothing, household supplies, food and other goods and services. Agricultural workers in some cases were also given access to plots of land to cultivate, including via share tenancy arrangements (van Onselen, 1996).

As a result of prior discriminatory labour policies, there existed the potential for labour unions and other changes associated with the end of apartheid to increase the bargaining power of black agricultural workers in South Africa for higher wages. As a result, commercial farmers accustomed to an abundant supply of inexpensive labour are finding it increasingly difficult to compete. Some farmers report that while they had previously kept an excess supply of labour on the farm to meet seasonal periods of high activity, they are no longer able to do so (Kirsten, 1998). Using the same data and methods from the previous analyses of agricultural productivity in South Africa and Zimbabwe, the linkages between labour quality and agricultural productivity can be explored. In particular, how sensitive productivity estimates may be to changes in human capital investment and restrictive labour policies is considered. A Cobb-Douglas production function, which embodies unitary elasticity of substitution, is assumed. The labour aggregate is adjusted for the numbers of domestic servants and part-time farm employees, and the salaries for the different racial and gender categories are then multiplied by the numbers of each, in order to calculate a total money wage. The estimated value of in-kind wages is then added as a lump sum.

FIGURE 7.5
TFP in Zimbabwe's Commercial Agricultural Sector

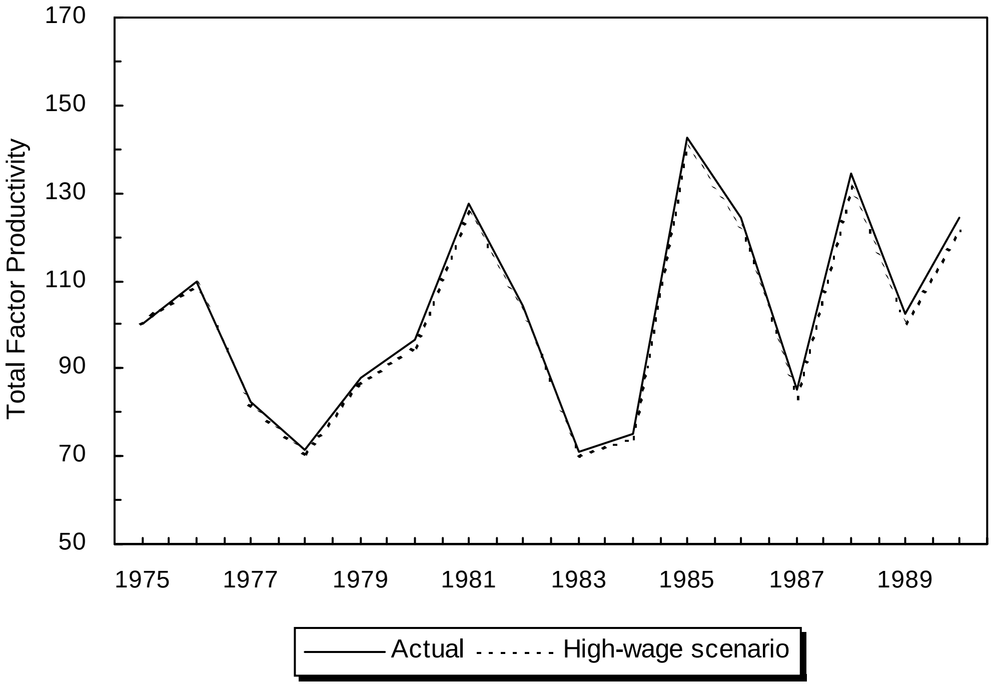


For this exercise, it is assumed that agricultural wage rates double with human capital investments, minimum wage legislation, labour union activities and the loosening of other restrictions on labour associated with independence and the end of the apartheid era. In keeping with the assumptions of the Cobb-Douglas model, the quantity of labour employed would be halved, keeping the overall wage bill constant. Working with the original spreadsheets, the effect of such a change on estimated agricultural productivity in the commercial and communal agricultural sectors of Zimbabwe and the commercial agricultural sector of South Africa is examined.

Based on the original labour data in South Africa's commercial agricultural sector, estimated TFP grew from a base of 100 in the late 1940s to more than 140 in the late 1980s, before falling back to about 130 in the early 1990s (Figure 7.1). By imposing the experimental change described above, doubling agricultural wages and halving agricultural labour employed, it is found that estimated TFP rises by more than 15 percent by the end of the period (Figure 7.4). This result can be explained by the substantial distortions that characterized South Africa's commercial agricultural sector throughout much of this period, especially those that resulted in the maintenance of excess supplies of labour in agriculture. In particular, if unskilled labour was employed in commercial agriculture to the point where its marginal product was not only low but actually negative, then reducing the amount of labour employed could increase efficiency and help explain the experimental result. However, it is important here to draw a careful distinction between estimates of productivity and efficiency, on the one hand, and implications for equity and social welfare on the other.

The same experiment can be performed on the data from Zimbabwe. As depicted in Figure 7.2, estimated TFP in Zimbabwe's commercial agricultural sector grew from a base of 100 in 1970 to about 220 in 1989. When wages are doubled and agricultural employment halved, estimated TFP is unchanged over the first decade, until about the time of independence in

FIGURE 7.6
TFP in Zimbabwe's Communal Agricultural Sector



1980, but then falls by about five percent relative to the original estimate over the course of the subsequent decade (Figure 7.5). Several factors are probably at work here. Agricultural inputs other than labour, like tractors, seeds and fertilizer, were far less readily available in Zimbabwe before 1980 than in South Africa. This was partially due to macro-economic policies to restrict imports of foreign technology. The concerns at the time were with maintaining a balance of payments, but the effect would have been to increase reliance on agricultural labour in Zimbabwe. Whereas in South Africa, agricultural labour would have been busy only during peak seasons, in Zimbabwe this condition would have persisted most of the time. With independence came a new set of policies designed to promote the adoption of modern technology, especially in maize production, and to increase opportunities for black farmers in the communal sector. It is at this time that increased demand for agricultural labour in the commercial sector would have manifested itself in Zimbabwe. In such circumstances, reducing labour employed while increasing wages, as in this experiment, would result in a decrease in productivity, particularly after independence in 1980.

The improved opportunities for blacks in Zimbabwe following independence resulted in part from specific government policies to improve conditions in communal agriculture. Original estimates of TFP in Zimbabwe's communal agricultural sector depicted in Figure 7.3 reveal a slight upward trend that is dominated by wide variability over the 15-year period. In contrast to findings for the commercial sectors in Zimbabwe and South Africa, repeating the same experiment of doubling wages and halving agricultural employment in this sector results in no systematic change in estimated TFP (Figure 7.6). In terms of the earlier analysis of results for other sectors and countries, this could imply the absence of labour market distortions in the communal sector. Alternatively, and perhaps more likely, is the possibility that the communal sector relies on non-marketed (and thus unmeasured) inputs and outputs to such an extent that neither the original nor the experimental estimates of TFP fully capture what is happening on many African smallholdings. Furthermore, white labour in Zimbabwe's communal sector is virtually non-existent; if the experiment is interpreted in terms of a change in the quality of the labour input as proxied by racial differences, no change in TFP would be expected. Since the labour input is undifferentiated, changes that hold labour's share constant have no effect. Investments in educational infrastructure might be expected to increase the quality of the unskilled agricultural labour input, but as no substantial investments of this kind were made in the communal sector, no effect on TFP from the experiment are apparent.

Results of this experiment in the three agricultural sectors suggest that when data are scarce, estimates of TFP may be sensitive to alternative assumptions about differences in human capital investment, particularly in the context of policy distortions. This sensitivity may be reduced in cases, such as Zimbabwe's communal agricultural sector, where technology is relatively homogeneous.

7.6 Summary and conclusions

Indicators of agricultural productivity show mixed trends in Zimbabwe and South Africa. Such partial measures as cereal yields are higher in the two countries than they are, on average, in sub-Saharan Africa as a whole. But land productivity in both Zimbabwe and South Africa is lower in terms of the value of agricultural output per hectare, and is growing more slowly, than it is in sub-Saharan Africa as a whole. Labour productivity is somewhat lower in Zimbabwe than it is in sub-Saharan Africa as a whole, and declined in both cases from 1980 to 1995. By contrast, labour productivity in South African agriculture is much higher, and grew over the same period. In terms of welfare implications, however, wage data in South Africa reveal sharp disparities in payments by race and sector, with black agricultural labour at the bottom of the scale.

As for more complete measures of agricultural productivity, Atkins and Thirtle (1995) estimated that total factor productivity (TFP) in Zimbabwe's communal sector grew by 8.1 percent annually in the early 1980s. The subsequent fall by 2.7 percent per year for the remainder of the decade was driven by reduced spending for costly post-independence policies supporting smallholder production, and also influenced by weather variation. In contrast, TFP growth in Zimbabwe's commercial sector was relatively stable, at about 4.0 percent annually in the 1970s and 1980s (Thirtle *et al.*, 1993). TFP grew at an average annual rate of 1.3 percent in South Africa's commercial agricultural sector between 1947 and 1991, accelerating to 2.9 percent per year in the final decade leading up to independence (Thirtle, Sartorius von Bach and van Zyl, 1993). These rates compare with an average annual TFP growth rate of 1.3 percent for sub-Saharan Africa as a whole (with wide variation among countries) over the past three decades.

Of critical importance in facilitating increased efficiency in the use of conventional inputs is improved infrastructure. Jayne and Jones (1997) argue that policy in some areas must address two fundamental constraints, the first of which is infrastructure, and specifically weak transportation and communication systems. Poor infrastructure results in high transactions costs, reducing the ability of farmers to compete in both input and output markets.

The second fundamental constraint they identify is the need for increased investment in agricultural research to improve productivity growth and increase the stability of regional food production and prices. In this regard, productivity analysis that fails to account for policy changes and differences in the quality of infrastructure may overestimate payoffs to R&D, when in fact R&D may not generate the returns expected without complementary investments in physical and institutional infrastructure.

Similar biases are introduced by the lack of information on the quality of both conventional and non-conventional inputs to agricultural production. Lack of data on changes in resource quality over time, and on the physical relationships between such changes and agricultural production, remain formidable obstacles to projections of productivity trends into the future. The lack of information on non-market inputs and non-marketed outputs also poses challenges for measurement and analysis of agricultural productivity in sub-Saharan Africa, particularly in the smallholder sector. These limitations are evident in section 7.5, for example, in the observed lack of sensitivity of TFP estimates to experimental changes in wage and employment levels in Zimbabwe's communal agricultural sector.

Observed productivity trends, in conjunction with projected population growth, continue to warrant concerns about the prospects for sustainable production, income generation and food security in commercial and smallholder agriculture, both in Zimbabwe and South Africa in particular and in sub-Saharan Africa more generally. Commercial agriculture in South Africa demonstrates the potential benefits of investments in infrastructure, human capital and research, which are simultaneously needed to facilitate efficient use of conventional agricultural inputs and marketing of agricultural outputs. As Jayne *et al.* (1994) suggest, the challenge for sub-Saharan African countries facing budget pressures is how to redesign rather than abandon policy efforts to raise agricultural productivity in a sustainable fashion. At least as challenging is the need for further attention on the part of researchers and policy-makers to the equity implications of the alternative policy and investment strategies.

References

Atkins, J. & Thirtle, C. 1995. The productivity of communal agriculture in Zimbabwe, 1975-90. *Oxford Agrarian Studies,* 23(2): 99-115.

Carter, M.R. & Wiebe, K.D. 1990. Access to capital and its impact on agrarian structure and productivity in Kenya. *American Journal of Agricultural Economics,* 72(5): 1156-1150.

Central Statistical Office, Government of Zimbabwe. Annual. *Production account, communal farming lands.* Harare.

Dalton, T.J., Masters, W.A. & Foster, K.A. 1997. Production costs and input substitution in Zimbabwe's smallholder agriculture. *Agricultural Economics,* 17(2-3): 201-209.

Deininger, K. & Binswanger, H.P. 1995. Rent seeking and the development of large-scale agriculture in Kenya, South Africa and Zimbabwe. *Economic Development and Cultural Change,* 43: 493-522.

Eicher, C.K. 1995. Zimbabwe's maize-based green revolution: preconditions for replication. *World Development,* 23(5): 805-818.

Eicher, C.K. & Rukuni, M. 1990. Zimbabwe's experience in restructuring institutions to support communal farmers: lessons for Namibia. *In* C. Csaki, T. Dams, D. Metzger & J. van Zyl, eds. *Agricultural restructuring in southern Africa*. Windhoek, Namibia: International Association of Agricultural Economists.

Hudson, N.W. & Jackson, D.C. 1959. Results achieved in the measurement of erosion and runoff in southern Rhodesia. Inter-African Soils Conference. Dalaba, Central African Republic.

Jayne, T.S. & Jones, S. 1997. Food marketing and pricing policy in eastern and southern Africa: a survey. *World Development,* 25(9): 1505-1527.

Jayne, T.S., Khatri, Y., Thirtle, C. & Reardon, T. 1994. Determinants of productivity change using a profit function: smallholder agriculture in Zimbabwe. *American Journal of Agricultural Economics,* 76: 613-618.

Jayne, T.S., Rubey, L., Chisvo, M. & Weber, M.T. 1996. Zimbabwe food security success story: maize market reforms improve access to food even while government eliminates food subsidies. *Policy Synthesis No. 18*, Office of Sustainable Development and Office of Agriculture and Food Security, Global Bureau, USAID. April.

Kassier, W.E. & Groenewald, J.A. 1990. The agricultural economy of South Africa. In C. Csaki, T. Dams, D. Metzger & J. van Zyl, eds. *Agricultural restructuring in southern Africa.* Windhoek, Namibia: International Association of Agricultural Economists.

Khatri, Y., Thirtle, C. & van Zyl, J. 1996. Public research and development as a source of productivity change in South African agriculture. *South African Journal of Science,* 92: 1-9 (*galley proof*).

Kirsten, J. 1998. Personal communication. (Chair, Department of Agricultural Economics, University of Pretoria, Gauteng, South Africa).

Lal, R. 1998. Soil erosion impact on agronomic productivity and environment quality. *Critical Reviews in Plant Sciences,* 17(4): 319-464.

Marquette, C.M. 1997. Current poverty, structural adjustment and drought in Zimbabwe. *World Development,* 25(7): 1141-1149.

Meinzen-Dick, R.S. & Rosegrant, M.W. 1997. Managing water supply and demand in southern Africa. In L. Haddad, ed. *Achieving food security in southern Africa.* Washington, DC: International Food Policy Research Institute.

Mudimu, G.D. 1990. Achieving and maintaining national and household food security: Zimbabwe's experience and issues for the 1990s. *In* C. Csaki, T. Dams, D. Metzger & J. van Zyl, eds. *Agricultural restructuring in southern Africa.* Windhoek, Namibia: International Association of Agricultural Economists.

Paul, P. & Abey, R. 1984. Conceptual issues in measuring productivity growth. Paper presented at the 28th Annual Conference of the Australian Agricultural Economics Society, Sydney, February.

Republic of Zimbabwe. 1981. *Growth with equity.* Harare.

Rohrbach, D.D. 1990. Strengthening crop production and marketing systems for semi-arid areas in the SADCC region. *In* C. Csaki, T. Dams, D. Metzger & J. van Zyl, eds. *Agricultural restructuring in southern Africa*. Windhoek, Namibia: International Association of Agricultural Economists.

Rubey, L. & Lupi, F. 1997. Predicting the effects of market reform in Zimbabwe: a stated preference approach. *American Journal of Agricultural Economics,* 79(1): 89-99.

Tagwira, F. 1992. Soil erosion and conservation techniques for sustainable crop production in Zimbabwe. *Journal of Soil and Water Conservation,* 47: 370-374.

Thirtle, C., Atkins, J., Bottomley, P., Gonese, N., Govereh, J. & Khatri, Y. 1993. Agricultural productivity in Zimbabwe, 1970-90. *Economic Journal,* 103: 474-480.

Thirtle, C., Sartorius von Bach, H. & van Zyl, J. 1993. Total factor productivity in South African agriculture, 1947-91. *Development Southern Africa,* 10(3): 301-318.

Thirtle, C., Townsend, R. & van Zyl, J. 1998. Testing the induced innovation hypothesis: an error correction model of South African agriculture. *Agricultural Economics,* 19(1-2): 145-157.

United States Department of Agriculture. 1980. *Measurement of US agricultural research productivity: a review of current statistics and proposals for change*. Technical Bulletin No.1614, Economics, Statistics and Cooperatives Service, Washington, D.C.

University of Zimbabwe & Michigan State University. 1992. *Documentation system summary: a guide to the Zimbabwe food security and marketing 1990-92: survey data.* Harare.

van Onselen, C. 1996. *The seed is mine: the life of Kas Maine, a South African sharecropper, 1984-1985*. Hill & Wang Publishers, ISBN 080909603X.

van Schalkwyk, H. & Groenewald, J. 1992. Regional analysis of South African agricultural resource use and productivity. *Agrekon,* 31(3): 116-127.

van Zyl, J., Fenyes, T.I. & Vink, N. 1992. Effects of the farmer support programme and changes in marketing policies on maize production in South Africa. *Journal of Agricultural Economics,* 43(3): 466-476.

van Zyl, J. & Groenewald, J.A. 1988. Effects of protection on South African commercial agriculture. *Journal of Agricultural Economics,* 39(3): 387-401.

van Zyl, J., Vink, N. & Fenyes, T.I. 1987. Labour-related structural trends in South African maize production. *Agricultural Economics,* 1(3): 241-258.

World Bank. 1998. *1998 world development indicators*. Washington, DC: The World Bank.

World Resources Institute, United Nations Environment Programme, United Nations Development Programme & the World Bank. 1998. *World resources 1998-99.* New York: Oxford University Press.

8. Determinants of agricultural investment by small-scale producers in Peru

Jackeline Velazco and Lydia Zepeda[1]

A survey of 155 small agricultural producers in the Central Sierra of Peru found that the majority of families invest less than US$385 per year (based on the 1996/97 agricultural year). Characteristics of investing (52 percent) and non-investing households (48 percent) are investigated. Income, savings and credit are all higher among investing households than non-investing households. Among the findings are that female-headed are more likely to invest than male-headed households and Quechua-speaking households are more likely to invest than Spanish-speaking households. The survey reveals that the majority of agricultural investments (69 percent by value) are not registered in the national agricultural census, indicating a serious omission in the national database. The survey also reveals the importance of local funding to finance small producers' investments. Nearly three-quarters (71 percent) of the investments were financed with family or communal funds. In addition, 45 percent of investments occurred with communal assistance, such as labour or sponsorship, indicating the importance of social networks. When asked about investment priorities, reforestation was the most desired future investment, followed by acquisition of more breeding livestock.

8.1 Introduction

For small agricultural producers food security is synonymous with adequate production. They may eat much of what they produce or sell it to buy food and other items. Their ability to produce enough to ensure household food security depends on the amount and quality of resources they have available (land, labour, seed, tools, etc.). Investments in the quantity or quality of household resources enhance their production capacity. For example, small producers can acquire more land or improve existing land by fencing, irrigation, terracing, or other methods.

In order to understand how agricultural investments enhance production capacity and productivity, one must have accurate data on investments and understand what factors influence decisions to invest. Most countries collect data on land use and improvements, agricultural

[1] The authors are grateful to all the following individuals who gave freely of their time and effort. Officials of SEPAR (an NGO based in Huancayo) provided contact with Ifigenia Meza of Quilcas and Irene Castro of Pazos, women leaders of the peasant community who played a key role in introducing the survey team to members of the communities. Gratitude is expressed to the Mayor of Quilcas, Daniel Rivas, for permission to use the Municipality's facilities while we were conducting the fieldwork in his community. Thanks are also due to the Mayor of Pazos, Zócimo Romero, the leaders of the peasant communities and each and every one of the 155 families who invited us into their homes and who shared their problems and hopes.
The Universidad Nacional del Centro participated in the study through the Dean of Social Sciences and, in particular, through Professor Norma Condezo, who was invariably willing to provide whatever assistance was required. The field work could not have been completed successfully without the efficiency, enthusiasm and hard work of the students of the Universidad Nacional del Centro of Huancayo who worked as interviewers: Angel Ccari (field supervisor), Daniel Rodríguez, Liz Obispo, Maribel Huarcaya, Luis Fabián, Cristina Navarro, Zulma Tiana and Nilda Paytan. Alberto Núñez was involved in all phases of the study and was in charge of processing the survey results. He was assisted in this task by Verónica Laos and Iván Rivera.

machinery and livestock. Changes in these series reflect gross agricultural investment. However, these series reflect the investments of larger producers rather than the more vulnerable small producer. For example, many small producers may not utilize machinery, but do invest in manual tools to enhance production. In addition, national data series on investment reflect an exploitative rather than regenerative relationship with natural resources. Land "improvements" generally include clearing land of natural vegetation, but not reforestation.

The primary objective of this study is to determine what factors influence the investment decisions of the most vulnerable group of agricultural producers, small peasant households. In addition, future investment priorities of small producers are investigated. A second overall objective is to determine what types of small-producer investments are captured by and reflected in the Agricultural Census, as well as to estimate their value. This has implications for tracking small producers' investments that in turn are necessary to implement programmes and policies to encourage investment and enhance productivity.

These questions will be investigated utilizing a survey of 155 small producers in the Central Sierra of Peru. Households in this region rely upon agriculture as the primary source of income and food. Agriculture is dominated by small producers in the region, most of whom produce for autoconsumption. Two representative communities were interviewed: Quilcas and Pazos, in the Departments of Junín and Huancavelica, respectively. These communities differ in their proximity to the major market of Huancayo as well as in ethnicity. Quilcas is exclusively Spanish-speaking, while Pazos has a large Quechua-speaking population.

The sample has been divided into two groups: households that made investments and those that made no investments in their production capacity during the 1996/97 crop year. Characteristics of each group are identified and compared. Variables considered include: the frequency of various types of investments, the demographic and production-related characteristics of the households, their sources of income, savings and borrowing patterns, capital assets, the way in which the women's time was distributed and decision-making roles with regard to various farm tasks.

The following section describes how the survey data were collected and provides general information about the areas selected for the study. The subsequent sections investigate characteristics of investing and non-investing small producers including socio-demographic traits of the households, characteristics of their production activities and amount and sources of income. The survey findings are compared with the Agricultural Census returns in order to determine what types of investments made by small-scale producers are reflected in national statistics. Correlation statistics of investment and particular variables are calculated. The role of women in investment decision-making and how it is related to their time use is also investigated.

8.2 Study sites and data collection

The study entailed working with rural households in the highlands of Peru. These households rely primarily on agriculture, are poor and have small landholdings. Much of their production is for autoconsumption. Their use of inputs and levels of investment are lower than in the export oriented coastal regions.

Huancayo is the capital city of the Department of Junín located in the central highlands of Peru. It is typical of the highlands of Peru. Due to the mountainous terrain, Huancayo is accessible primarily by ground transportation. It is located about eight hours east of Lima.

The town of Quilcas was chosen as the site for the pilot survey. Quilcas is located at a distance of three km from Huancayo at an altitude of 3 300 metres above sea level. In 1993, the district of Quilcas had a population of 3 508, with 53 percent of the population living in town and 47 percent in the outlying, rural area (INEI, 1996).

For purposes of comparison, a second community located at a distance from Huancayo was sought and the institutional contacts that were made led to the selection of the community of Pazos. The community of Pazos is located in Tayacaja Province in the Department of Huancavelica at a distance of 26 km from the city of Huancayo and at an altitude of 3 840 metres above sea level. As of 1993 (INEI, 1996), it had a population of 7 805, with 22 percent of the inhabitants living in town and 78 percent in the rural zone. Quechua is the mother tongue for 47 percent of the population, followed by Spanish with 35 percent.

The relative distance separating these two communities from the city of Huancayo represents their ability to market their agricultural products, seek off-farm income, purchase needed productive inputs and access services. By public transportation it takes only 15 minutes to reach Quilcas from Huancayo, whereas the trip to Pazos takes an hour. Quilcas can be reached via regularly scheduled public transportation that operates all day, every day (until 2200 hours). Pazos, on the other hand, has regularly scheduled transportation service only between 0600 hours and noon on Saturdays (the day the open-air market is held). During the rest of the week, transportation is via private vehicle (farm trucks and vans) or buses that occasionally pass through the town.

Both communities rely predominantly on agriculture for income. In Quilcas, 61 percent of the economically active population is employed in resource-based industries (agriculture, livestock, hunting, forestry and mining and quarrying), 25 percent in service activities and 14 percent in manufacturing. Most agricultural producers have small landholdings and are poor. A total of 80.2 percent of the children in the first year of primary school suffer from chronic malnutrition and women head 34.4 percent of households. As an indicator of housing conditions, 27 percent of the households in the district of Quilcas lack sewers, running water and electricity, 40 percent have neither running water nor sewer systems and 52 percent do not have electricity. Regarding education, 13 percent of the population aged five and above has had no education, 55 percent have a primary education and 22 percent have a secondary education (INEI, 1994).

In Pazos, an estimated 89 percent of the economically active population is employed in resource-based industries (agriculture and livestock), seven percent in services and four percent in manufacturing. A total of 78 percent of the children in the first year of primary school are chronically undernourished and women head 23.5 percent of households. With regard to housing conditions, 53 percent of the households lack sewers, running water and electricity, 57 percent have neither running water nor sewer systems and 85 percent do not have electricity. As for education, 22 percent have had no education, 56 percent have a primary education and 16 percent have a secondary education (INEI, 1994).

The differences between the two areas can be accounted for by Quilcas' proximity to the bustling urban centre of Huancayo. In relative terms, when compared with the population of Pazos, the people of Quilcas are more educated and have greater access to running water, sewer systems and electricity. In economic terms, the population of Pazos is primarily rural and farming and animal husbandry are the main occupations. In contrast, the population of Quilcas is fairly evenly distributed between rural and urban areas and is more diversified among farming, animal husbandry, manufacturing and services.

Selection of the sample

The size of the sample was set at 155 households: 85 in Pazos and 70 in Quilcas (the difference in number being justified by the fact that Pazos has a larger population). In making up the survey sample, the following selection criteria were used:

- Peasant households whose principal activities are agriculture and/or animal husbandry.
- Households with small landholdings that are regarded as poor by informed individuals.
- An effort was made to select households located in different hamlets to ensure that the sample would be spatially representative.
- Regarding the gender of the household head, an effort was made to approximate the distribution identified in the 1994 Agricultural Census (i.e. women are the heads of 28 percent of the households in Junín and of 26 percent of the households in Huancavelica).

8.3 Investment and socio-demographic traits of peasant households

The following sections are based on the survey results for the sample, which was divided into those households that made some sort of productive investment in the 1996/97 crop year and those that did not. These represent profiles of investor and non-investor families. As part of this analysis, an attempt will be made to identify particular features of each of the two groups.

The investments made by these households on their farms mainly involved the construction of boundary markers, fences, ditches or channels and irrigation infrastructure (Velazco, 1998, Table 6.1.2). The average value of those families investing was 692 New Soles[2] (US$266). Table 8.1 shows the different ranges of investment levels, broken down by district. The results show that 31 percent of the households in Pazos made no investment while 69 percent did invest. As for the amounts invested, 53 percent of the latter category of households invested less than 200 New Soles, 29 percent invested between 200 and 1 000 New Soles and 18 percent invested more than 1 000 New Soles.

Table 8.1 Distribution of the value of investment by community

	Pazos		Quilcas		Total	
	Cases	Percent	Cases	Percent	Cases	Percent
No investment	26	30.6	49	70	75	48.4
1-50 New Soles	11	12.9	8	11.4	19	12.3
51- 200 New Soles	20	23.5	4	5.7	24	15.5
201-500 New Soles	8	9.4	2	2.9	10	6.4
501-1 000 New Soles	9	10.6	3	4.3	12	7.7
1 001-2 000 New Soles	5	5.9	1	1.4	6	3.9
2 001-3 000 New Soles	4	4.7	1	1.4	5	3.2
> 3 000 New Soles	2	2.4	2	2.9	4	2.6
Total	85	100	70	100	155	100

Note: At the time of the survey, the exchange rate was US$1.00 = 2.6 New Soles.

In the case of Quilcas, 70 percent of the households did not make any investment and 30 percent did. The breakdown of the sums invested is as follows: 57 percent invested less than 200 New Soles, 24 percent invested between 200 and 1 000 New Soles and 19 percent invested more than 1 000 New Soles.

The distribution of investment levels in the two communities is apparently similar, although a majority of the households in Quilcas did not make any investment. When household members were asked to state the main reason why they did not make any investment in their farm, 61 percent of all the non-investor households felt “it wasn’t necessary” and 34 percent said it was because of a “lack of money”.

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2 At the time the survey was conducted, February-March 1998, the exchange rate was US$ 1.00 = 2.60 New Soles.

In order to examine how farm income is related to investment, Table 8.2 shows what the farmers thought about the prices received for the agricultural products they sold. A majority thought that the price levels for the 1996/97 crop year were not good. Investors and non-investors alike shared this opinion. Thus, invest-ments were not being driven by exclusively by returns to products.

Table 8.2 Small-producer opinions about prices received for agricultural products

	Prices were good	Prices were not good	Total
Pazos families			82
Investors	15	43	58
Non-nvestors	4	20	24
Quilcas families			31
Investors	0	10	10
Non-investors	1	20	21
All families			113
Investors	15	53	68
Non-investors	5	40	45

In both Quilcas and Pazos, the population is organized on the basis of farm family units. Insofar as the household structure is concerned (Table 8.3), the average size of the investor families is 5.57 members and that of the non-investor families is 5.65. The average number of children per family is 4.03 and 3.65, respectively.

Table 8.3 Demographic characteristics of survey households

	Investors			Non-investors		
	Pazos	Quilcas	Total	Pazos	Quilcas	Total
Number of households	59	21	80	26	49	75
Household size	5.5	6.4	5.8	5.4	5.8	5.7
Number of children	4.0	4.1	4.03	3.6	3.7	3.65
Household head						
Age (years)	42.2	45.5	43.1	40.7	44.6	43.2
Years living in community	38.6	35.1	37.7	38.7	40.8	40.1
Male HH heads (percent)	78	57	73	80	76	77
Female HH heads (percent)	22	43	28	20	24	23
Level of education (percent):						
None	10	14	11	0	7	4.2
Primary	34	48	38	40	50	46.5
Secondary	54	38	50	56	41	46.5
Technical	0	0	0	4	0	1.4
University	2	0	1	0	2	1.4
If not completed primary school, can (percent):						
Read a newspaper	67	64	66	63	56	58
Write a letter	67	64	66	50	63	58
Speak fluent Spanish	79	100	86	88	100	96
Mother tongue (percent):						
Spanish	30.5	95	47.5	40	100	79
Quechua	69.5	5	52.5	60	0	21

A majority of household heads is male. However, in the case of Quilcas, far more heads of investing households were female (43 percent) than in Pazos (22 percent). Among investor families, 11 percent of the heads of household have had no formal education at all, 37.5 percent have a primary education and 50 percent have a secondary education. Among the non-investor families, 4.2 percent of the heads of household have had no formal education whatsoever and 46.5 percent have attended primary and/or secondary school.

8.4 Investment and characteristics of the households' production activities

An examination of the activities performed by these households attests that the chief activity of the households is agriculture. Given the environment in which these families live, the most significant development to be noted is how they have diversified their production activities around their agricultural, land-based core activity (Table 8.4). Most of the crops are rain-fed; the use of irrigation is very limited. The types of crops vary, but the most common ones are potatoes, maize and natural pastures (Table 8.5).

Land is an asset that is in scarce supply, but even though it is a highly limited factor of production, it serves as the foundation for the principal activity of these family units. Most farms are very small (Table 8.6). Of the investor families, 28.75 percent own less than one hectare, 42.5 percent own one to three hectares and 29 percent own more than three hectares. Among non-investor families, 66.7 percent own less than one hectare, 15 percent own one to three hectares and 19 percent own more than three hectares. Not all the plots of land owned by these families are similar in size or soil quality. These circumstances are reflected in differences in production and income-generation among the households. The area of cultivated land is related significantly to investment of the overall sample and Quilcas, in particular.

Surprisingly, the yields of the non-investor households' potato, maize and broad bean crops were higher than those of investors. In addition, the coefficients of variation for these households were higher as well, which indicates that the yields per hectare vary more. These yield differences occur despite the fact that investors (20 percent) are more likely than non-investors (12 percent) to have water year round (Table 8.7). There were no differences in how the land was distributed among uses (Table 8.8). Nor were there differences found between the two types of households' patterns of fertilizer use (Table 8.7). Investors tend to own a higher proportion of their land (88 percent) than non-investors (79 percent) do (Table 8.8).

Table 8.4 Distribution of household income and expenses (percent)

	Investors			Non-investors		
	Quilcas	Pazos	Total	Quilcas	Pazos	Total
Income Source						
Crops	32	57	48	51	59	55
Crop derivatives	<1	4	2	1	7	3
Livestock products	8	1	4	4	1	3
Wages	27	20	22	33	24	29
Occasional activities	1	1	1	<1	0	0
Sale of animals	32	17	23	11	9	10
Agricultural Expenses						
Livestock purchases	22	22	22	22	4	16
Crop activities	48	68	56	65	88	73
Livestock activities	30	10	22	13	8	11

Table 8.5 Distribution of principle crops as a percent of cultivated parcels (percent)

	Investors			Non-investors		
	Pazos	Quilcas	Total	Pazos	Quilcas	Total
Potato	62	33	55	64	31	45
Maize	4	46	12	2	41	25
Peas	3		3	3	1	2
Beans	7	8	7	7	7	7
Olluco (a tuber)	7	4	6	2	2	2
Barley	1		1	5	1	2
Oca oxalis (a tuber)	3		3	3		1
Oats	3		3	4		2
Quinoa (a grain)	1		1	3		1
Natural pasture	7	9	7	3	15	10
Improved pasture	1		1	1	2	2
Mashwa (a tuber)	1		1	3		1

Table 8.6 Production characteristics of households

	Investors			Non-investors		
	Pazos	Quilcas	Total	Pazos	Quilcas	Total
Households	59	21	80	26	49	75
Cultivated area (ha)	2.2	1.3*	1.97*	1.5	0.7*	0.99*
Parcels per household	8.2	5	7.4	8.7	4.8	6.2
Farm Size (percent):						
< 0.5 ha	5	57	19	27	63	51
0.5-1.0 ha	12	5	10	23	12	16
1.1-2.0 ha	34	5	26	19	4	9
2.1-3.0 ha	17	14	16	4	6	5
3.1-4.0 ha	8	5	8	4	2	3
>4.0 ha	24	14	21	23	13	16
Production 1996/97:						
Potato area (ha)	0.41	0.57	0.43	0.33	2.62	1.23
Potato yield (kg/ha)	8 333	9 648	8 491	10 151	17 050	12 860
Maize area (ha)	0.28	0.15	0.18	0.15	0.11	0.11
Maize yield (kg/ha)	3 769	7 197	6 297	13 226	8 277	8 442
Bean area (ha)	0.34	0.25	0.32	0.12	0.09	0.10
Bean yield (kg/ha)	7 444	4 504	6 686	10 321	16 350	13 697
Crop Utilization (percent):						
Potato						
Autoconsumption	13	12.5	12.9	12	17.5	14.7
Sale	75	80.8	76.2	70.6	66	68.4
Barter	1	0.4	0.9	0.9	0.5	0.7
Seed	11	6.3	10.0	16.5	16	16.2
Maize						
Autoconsumption	9.7	53.7	32.3	11.3	45.9	42
Sale	81.9	26.1	53.3	84	38.6	44
Barter	0	4.8	2.5	0.25	2.4	2.1
Seed	8.4	15.4	11.9	4.45	13.1	11.9
Beans						
Autoconsumption	37.1	47.7	37.9	20.7	54.2	47
Sale	54.4	25.2	52.1	68.9	30.4	38.6
Barter	0.7	0.9	0.7	2.1	2.7	2.5
Seed	7.8	26.2	9.3	8.3	12.7	11.9

*significant at five percent level

Table 8.7 Availability of water and use of fertilizers on parcels of survey households

	Investors			Non-investors		
	Pazos	Quilcas	Total	Pazos	Quilcas	Total
Availability of water:						
Year-round	131	18	149	45	9	54
Part of year	80	24	104	29	129	158
Dryland	274	63	337	151	99	250
Total parcels	485	105	590	225	237	462
Type of fertilizer used for crops:						
Organic	76	30	106	22	53	75
Chemical	111	18	129	58	39	97
Both	129	40	169	57	84	141
Neither	62	9	71	14	35	49
Total parcels	378	97	475	151	211	362

Little difference was found in how the crops were utilized (Table 8.6). In the case of potatoes, the percentage of output that was sold was somewhat higher (77 percent) for investor households than non-investor households (68 percent), while the proportion used in barter was similar: 0.7 percent for non-investor households and 0.9 percent for investors. On-farm consumption was

Table 8.8 Use and tenancy of land of survey households

	Investors			Non-investors		
	Pazos	Quilcas	Total	Pazos	Quilcas	Total
Number of Parcels	485	105	590	225	237	462
Use of Parcel:						
Crops	348	89	437	144	178	322
Fallow	104	6	110	74	25	99
Pasture	27	8	35	7	31	38
Temporary Pasture	6	0	6	0	0	0
Crops and Pasture	0	0	0	0	3	3
Brick making	0	2	2	0	0	0
Type of Tenancy:						
Owned	431	86	517	179	186	365
Rented	15	14	29	2	30	32
Share-cropped	14	4	18	6	19	25
Communal	22	0	22	38	2	40
Partially rented	0	1	1	0	0	0
Appropriated	3	0	3	0	0	0

similar, 12.9 percent of production for investor households and 14.7 percent for non-investor households. A smaller proportion of potato seed was used among investor households, ten percent versus 16 percent for non-investors. This is consistent with the larger landholdings of investor families.

In the case of maize, on-farm consumption amounted to 32 percent for investor households and the amount sold represented 53.3 percent of total output. In the non-investor group, a similar pattern was found: 44 percent of the harvest was sold, 42 percent was used for on-farm consumption and the rest was used for barter and seed. Thus, a key conclusion to be drawn with regard to the use of farm output is that there is little difference between non-investor and investor households. The largest proportion of production is sold, followed by autoconsumption, seed and barter. In the case of maize and potato, the community of Pazos sells a larger percent. Given the greater proportion of potato sold in both communities, potatoes represent an important source of agricultural income.

Investment and the marketing of farm output

It is interesting to note that the community that is farther away from Huancayo, Pazos, uses this city as a commercial centre for the sale of its agricultural produce and processed goods, whereas the settlement that is closer to Huancayo, Quilcas, tends to sell its output within the community. When asked about where they sell their potatoes, 84 percent of the peasant farmers from Pazos said that they sell them in Huancayo and five percent said they market them within the community. In the case of Quilcas, the situation was more variable, with 18 percent selling their output in Huancayo, 18.2 percent marketing it outside the community, 32 percent in the community and 14 percent selling their produce on their farm to dealers (Velazco, 1998, Tables 2.5.1.3-2.5.3.6).

In the case of maize, 78 percent of the farmers from Pazos sell their output in Huancayo and the rest market it in the community. For the marketing of processed products (chuño, dried potatoes and poultry baskets), the main point of sale for Pazos' farmers is Huancayo (75 percent). For producers in Quilcas, these products are mainly offered within the community. In Pazos, animal products (milk, wool, cheese and eggs) are sold both in the community and in Huancayo, especially in the case of meat. In Quilcas, these products are offered chiefly within the community (Velazco, 1998, Tables 2.5.1.3-2.5.3.6).

8.5 Investment and income structure

An analysis of the income structure in these communities demonstrates just how diversified are the activities conducted by these farm families (Table 8.4). In Quilcas, the investor households derive the largest portion of their income from the sale of farm animals (32 percent); their crops provide 31 percent of their income and wages are the source of 27 percent. For the non-investor households, livestock provides 11 percent of their income, crops generate 51 percent and wage labour accounts for 33 percent. In Pazos, the investor households obtain 57 percent of their monetary income from their crops, 20 percent from wage labour and 17 percent from livestock. The non-investor households follow the same pattern, with the corresponding figures being 59, 24 and nine percent, respectively.

Generally speaking, crops and livestock provide the bulk of these households' income. The amount of income derived from wages indicates the importance of labour migration as an income-supplementation strategy. Very little income is earned from products derived from crops or livestock.

The sale of farm animals is an important strategy, along with the sale of casual labour. In most cases livestock is the second-most important source of income, after crops. The survey did not reveal any significant difference between the two communities' patterns of livestock ownership (Velazco, 1998, Tables 2.7.2 and 2.7.3). In both cases the main types of animals that are raised are sheep, poultry, guinea pigs and pigs. Large livestock (oxen, horses and donkeys) are used as draught animals as well as a source of food and processed products for on-farm consumption or sale.

Livestock's importance as an income-generating strategy derives chiefly from the possibility of raising stock and smaller animals (poultry and guinea pigs) that can then be sold at the Sunday market; the income earned from their sale is used to purchase a limited amount of essential goods. In addition, they are an important source of protein for the family.

The ownership of livestock can be regarded as a form of savings for farm households. The main advantage is that in times of economic difficulty, the animals can be sold off and they thus offer the household a rapid and certain way of obtaining cash. Given the relatively greater importance of livestock sales to investor households, livestock sales may serve as a means of financing investments.

8.6 Comparing investment data to the Agricultural Census

The Agricultural Census gathers information on both modern and traditional types of capital assets used in crop farming and stock raising. The 1994 Census returns were largely corroborated by the survey findings in Pazos and Quilcas. The farmers own very little heavy agricultural machinery (only three tractors, one harvester, one electric generator and four pick-up trucks were counted) but own considerably more traditional types of equipment, including such implements as pitchforks, shovels, machetes, sickles, scythes, hand-held ploughs, picks and hoes. The types of capital goods used in livestock activities include harnesses, reins and straps, layer hens, improved stock, knives, milking machines, buckets, sacks, bags, shears and milk cows. The information collected in the survey also covers the condition of the equipment; most of the traditional equipment was classified as "used."

The Agricultural Census does not cover capital goods or assets relating to processing agricultural products. This omission may have serious implications in terms of those rural households that have diversified their activities and supplement crop-farming and stock-raising activities with income earned by the same household from the processing of agricultural inputs. In the Quilcas and Pazos survey, the following assets were identified: saws, hammers, sewing machines and milk containers, among others.

The items covered in both the survey of small-scale producers and the national census are: purchase of breeding stock, purchase of milk cows, nurseries, seedbeds, stables, dipping tanks, water troughs, fences, retaining walls, storehouses or tanks and workshops (INEI, 1996, section XIV, question 98). However, the Agricultural Census does not specify whether the purchases are recent or not (INEI, 1996, section VII, question 71), making it impossible to assess when investments were made. The survey of small-scale producers identifies investments made in the 1996/97 crop year.

Another serious consideration is that the quantity of the investment is recorded in the Agricultural Census, but not its value. For example, under agricultural facilities, the options given are storerooms or barns, shearing sheds, silos, reservoirs, chicken coops, milking sheds, dipping tanks, barbed-wire fences, electrified fences, chicken-wire fences, scaffolding and terraces (INEI, 1996, section XIV, question 98). The advantage offered by the survey of farm households is that it includes the cost of improvements, additional investments, investment financing and the households' or the community's participation in their execution.

In addition some of the items not covered in the Agricultural Census which are included under "investments and improvements" in the survey of small-scale producers are:

- Reforestation
- Permanent crops
- Ditches and channels
- Roads and bridges
- Running water and sewer connections
- Electricity hook-ups
- Training courses.

Using the data from the small-scale producer survey, Table 8.9 presents the value of the investments that are included in the Agricultural Census as well as those that are not. An average of only 31 percent of the value of the investments made by small-scale farmers would be recorded by the Census, which means that 69 percent was not. When broken down by community, only 17 percent of the investments in Quilcas would be recorded by the Agricultural Census, whereas 39 percent would be recorded in Pazos. This indicates that a majority of the investments made by small-scale producers are being omitted in the agrarian statistics compiled nationally.

Table 8.9 Value of small-scale agricultural investments (in New Soles)

Community	Total	Recorded in Census	Not recorded
Quilcas	15 898	2 820	13 078
Percent	100	17	83
Pazos	28 720	11 094	17 626
Percent	100	39	61
Total sample	44 618	13 914	30 704
Percent	100	31	69

Note: "Recorded" covers the items included in the 1994 Agricultural Census schedule: breeding stock, retaining walls, nurseries, seedbeds, dipping tanks, storehouses or tanks and workshops, fences and soil improvement. "Not Recorded" includes: reforestation, improvements in permanent crops, ditches and channels, roads, bridges, running water, electricity hook-ups, training courses, cropping improvements, home construction and improvements and others.

In the case of Pazos, the main investment items recorded include dipping tanks (36 percent), the construction of nurseries and seedbeds (27 percent) and retaining walls (13 percent). In all, 32 percent of the investments were carried out with help from the community and 64 percent were not. Some of the main types of investments that were not recorded were the construction of housing (24 percent), reforestation (21 percent), ditches and channels (14 percent) and improvements in the production of permanent crops (21 percent). On average, 32 percent of these investments were completed with community assistance and 63 percent were not.

In Quilcas, the recorded investments included the following items: dipping tanks (36 percent), nurseries and seedbeds (23 percent) and the purchase of milk cows (17 percent). In value terms, the community was involved in 35 percent of these investments and the investor households made 65 percent of these investments on their own. The unrecorded investments included the category "other"[2] (46 percent), roads and bridges (38 percent) and electricity hook-ups (12 percent). Community involvement was greatest in these cases (85 percent), since the community did not assist with only 15 percent of these investments, measured in terms of value.

The survey also revealed future investment priorities. In both communities, reforestation was the highest priority investment; 43.5 percent of households in Pazos and 24.3 percent in Quilcas chose it. This is particularly revealing that the highest investment priority of these small-scale producers is not identified in the national database as an investment. Clearly, this puts policy-makers and project designers at a disadvantage when attempting to develop appropriate policies and projects.

Purchase of breeding stock came in as the second most important priority for future investment for both Pazos' (29.4 percent) and Quilcas' (23 percent) households. Rounding out the third and fourth highest priorities for Quilcas were ditches and channels for irrigation (16 percent) and training course (11.4 percent) of households, respectively. Households in Pazos were in agreement about a larger array of future investment priorities: training courses (19 percent), fencing (19 percent), purchase of milk cows (19 percent) and ditches and channels for irrigation (18 percent).

8.7 Correlates and sources of small-scale investments

Table 8.10 provides a comparison of the average values of a series of variables for the investor and non-investor households. In the community of Pazos, investor households have more cash savings than non-investor households do. They also have greater access to credit, have higher levels of on-farm consumption and more cash and total farm income. In addition, investor households have more agricultural assets and more assets of the types used in the production of derived products, measured in terms of value. However, non-investor households have more livestock-related assets measured in value terms.

Table 8.10 Indicators of average household investment (in New Soles)

	Investors			Non-investors		
	Pazos	Quilcas	Total	Pazos	Quilcas	Total
Households (number)	59	21	80	26	49	75
Investment	622	888	692			
Cash Savings	298	785	426	171	0	59
Cash Credit	548	187	453	289	278	282
Autoconsumption	4 217	3 569	4 047	2 380	2 523	2 473
Agricultural Income	5 353	8 116	6 078	3 823	3 092	3 345
Cash Income	6 742	11 280	7 933	5 004	4 600	4 740
Total Income	10 959	14 849	11 980	7 384	7 123	7 213

In Quilcas, only investor households have cash savings. However, non-investor households have access to higher levels of credit. This situation may have something to do with this

[2] This category includes drainage ditches, growing potato crops for the use of the community, dredging ditches and channels, holding workshops and cleaning out gutters.

community's more diversified income structure, in which non-agricultural rural activities may demand more of these households' time and effort. As in the case of Pazos, the investor households have higher levels of on-farm consumption, agricultural income and total income. The non-investor households, on the other hand, have considerably higher levels of crop-farming, livestock and derived-product assets. This situation may reflect the relatively lower demand for production-related investments existing among the households in Quilcas, where many households said they had not invested because "it wasn't necessary;" in other words, they already had the production equipment and assets they needed.

Table 8.11 Correlation coefficients of total household investment and other variables

Variable	Total sample	Quilcas	Pazos
Crop-farming income	0.315*	0.45*	0.12
Agricultural income	0.291*	0.38*	0.14
Total monetary income	0.272*	0.35*	0.15
Spending on education	0.256*	0.33*	0.17
Total savings	0.438*	0.51*	0.31*
Hectares under cultivation	0.33*	0.56*	0.11
Education – head of household	0.083	0.03	0.19
Total value of assets	– 0.037	0.04	-0.01

*significant at five percent

Simple correlation coefficients are presented in Table 8.11 to identify relationships between household investment levels and other variables. This is done for the whole sample, investor households in Quilcas and investor households in Pazos. Although simple correlation statistics only identify linear relationships and do not determine causality, the following relationships were identified. A positive, statistically significant linear correlation exists between household investment and crop income, agricultural income and total cash income. The coefficients are statistically significant at 95 percent for the total sample and Quilcas; the degree of significance is lower for Pazos, but the direct correlation is still evident.

Investor households have the larger farms, that is, greater number of hectares under cultivation. Larger farms require more investment, and may generate sufficient income necessary to enable investment. The latter is supported by the fact that investor households have significantly more savings in both communities. This underscores the importance of savings as a source of investment financing.

The level of education of the household head and the value of total assets do not have any significant relationship with the households' decisions regarding productive investments. However, spending on education is significantly correlated with household investment for the whole sample and the community of Quilcas. Therefore, households with the predisposition and ability to invest in agriculture are also investing in human capital.

To investigate how investments and improvements have been financed, Table 8.12 shows the importance of local or internal financing. In Pazos, 60 percent of the funding for the

Table 8.12 Amount of investments according to source of funds for crop year 1996/97 (in New Soles)

	Pazos		Quilcas		Total	
	Amount	Percent	Amount	Percent	Amount	Percent
Family savings	10 228	35.5	7 125	45	17 353	39
Personal savings	3 128	11	523	3	3 651	8
Community	3 806	13	7 070	44	10 876	24
Personal loans	2 000	7	350	2	2 350	5
International cooperation	4 200	15	0	0	4 200	9
NGOs	2 500	8.5	0	0	2 500	7
Other	2 858	10	830	6	3 688	8
Total	28 720	100	15 898	100	44 618	100

investments made during the last crop year came from within the community itself (36 percent from household savings, 11 percent from personal savings and 13 percent from the community). Funding from external sources (NGOs, international cooperation, government agencies and personal loans) financed 40 percent of the investments in terms of value.

In Quilcas, few external sources of financing were found to exist, as attested to by the fact that 92 percent of the investments were funded internally (Table 8.12). Household savings provided 45 percent of the funding for improvements and investments, the community was the source of another 44 percent and personal savings accounted for three percent. It would appear that community and household savings are the main strategy used for financing productive investments.

In addition to providing financial support, the community is also important in providing the social support and organization to assist household investment. By value, 44.3 percent of household investments were carried out with community assistance (Velazco, 1998, Tables 6.1.3.1 and 6.1.3.5). Community assistance is particularly important in Quilcas where 65 percent of investments are community assisted. The level in Pazos is just 35 percent indicating potential for development of community assistance projects. Because much of this work is non-monetary in nature, either through provision of labour or facilitation, this form of investment is not identified in censuses or official statistics. Therefore, they undercount the level of productive investments made by households. Investments in which the community participates include the following: reforestation, permanent crops, ditches and channels, roads, bridges, nurseries, seedbeds, dipping tanks and training courses.

8.8 Gender and investment

An examination of the involvement of men and women in the types of investments and improvements made indicates that they participated to a similar degree in the following types of investments: reforestation, permanent crops, roads, bridges, nurseries, seedbeds, dipping tanks, training courses and home construction and improvements (Table 8.13). Males were more actively involved in the following categories: purchase of breeding stock and of milk cows, digging of irrigation ditches and channels, connections for running water, construction of retaining walls, storehouses and workshops, fencing and improvements in crop production and in soil quality.

Gender differentiation in investment decisions is related to differentiation of daily responsibilities. Women are primarily responsible for domestic matters and therefore actively participate in decisions related to domestic matters as well as closely related activities such as the distribution of production, pasturing, small-scale marketing and the production of handicrafts. Decisions usually made by the men are related to their daily responsibilities such as the assignment of field work, the

Table 8.13 Participation in investment and improvement during 1996/97 crop year (percent)

	Males	Females	Children
Reforestation	50	47	3
Perennial plantings	58	40	2
Purchase breeding stock	75	25	
Purchase dairy cows	100		
Irrigation canals	66	34	
Roads and bridges	51	49	
Water installation	100		
Retaining walls	85	15	
Nurseries, seedbeds	53	44	3
Electrification	100		
Dipping tanks	60	40	
Water troughs	37	50	13
Storage sheds	87	13	
Training courses	59	41	
Fencing	59	18	23
Soil improvements	74	26	

purchase of fertilizers, the use of fields, the purchase of seeds and the completion of paperwork and procedural arrangements.

Household income and the production system influence gender specialization of tasks. In poorer families, more active participation by all the members of the household is called for. Therefore, women play a more important role and often stand in for their sons or husbands. In the case of crops, men mainly do land preparation, while women are in charge of seed selection. In the area of animal husbandry, men are usually responsible for dipping animals and administering medicine, shearing and tending wounds; women are generally in charge of milking, feeding and pasturing. In the case of domestic chores, men are mainly responsible for carpentry, fencing and the hauling manure, while women and children cook and do laundry.

Daily activities of women

The survey corroborated the findings of previous studies that have demonstrated the economic importance of peasant women (Zevallos, 1994). The role played by these women is not limited to the types of domestic activities involved in reproduction and the daily and generational maintenance of the family but also includes a visible and active presence in production activities.

Table 8.14 Women's time use during different periods of 1996/97 crop year

	Harvest season		Planting season		Rest of year	
	Hours	Percent	Hours	Percent	Hours	Percent
Quilcas:						
Productive activities:	10	42	10	42	2.5	10.5
Planting	0	0	10	42	0	0
Harvesting	10	42	0	0	0	0
Livestock	0	0	0	0	2.5	10.5
Domestic activities:	6	25	6	25	13	54
Cooking	6	25	6	25	9.5	40
Wash clothes	0	0	0	0	1.5	6
House cleaning	0	0	0	0	2	8
Leisure:	8	33	8	33	8.5	35.5
Eating	2	8	2	8	2.5	10.5
Sleeping	4	17	4	17	4.5	19
TV	2	8	2	8	1.5	6
Total	24	100	24	100	24	100
Pazos:						
Productive activities:	10	42	9	37.5	1.5	6
Planting	0	0	9	37.5	0	0
Harvesting	10	42	0	0	0	0
Livestock	0	0	0	0	1.5	6
Domestic activities:	6	25	5	21	11.75	49
Cooking	4	17	4	17	8	33.3
Wash clothes	0	0	0	0	2.5	10.4
House cleaning	0	0	0	0	1	4.2
Child care	1.5	6	0	0	0	0
Husband care		0.5	2	1	4	0.25
Leisure:	8	33	10	41.5	10.75	45
Eating	4	16.5	6	25	4	17
Sleeping	4	16.5	4	16.5	5	21
TV	0	0	0	0	1.25	5
Conversation	0	0	0	0	0.25	1
Listen to radio		0	0	0	0	0.25
Total	24	100	24	100	24	100

Peasant women work alongside their husbands in the various stages of the agricultural production process (planting, harvesting, threshing, tending stock, cutting fodder, etc.). The range of production activities performed by women extends beyond crops to include handicrafts and raising livestock as well.

An examination of how women allocated their time to agricultural work shows that they work approximately ten hours a day during the harvest and 9.5 hours a day during the planting season. During the rest of the year their time is devoted mainly to domestic chores and care of animals. The time use data is reflective of their involvement in household decisions. They are involved in most agricultural decisions, but to a somewhat lesser degree than men. Women dominate domestic decisions; however, men have substantial control over spending decisions, even those related to domestic activities.

Table 8.14 indicates how women distribute their time among productive, reproductive and leisure activities. For women in Quilcas, during harvest and planting, production activities accounted for 42 percent of their day, reproductive activities for 25 percent, while leisure and personal care accounted for 33 percent of their day. During the rest of the year, production activities took up 10.5 percent of their time, reproductive activities accounted for 54 percent and personal care and leisure account for 35.5 percent. In Pazos, except during harvest, women spent somewhat less time than women in Quilcas did in productive and reproductive tasks.

The time use data indicate that women spend a substantial amount of time in domestic activities, particularly cooking. This severely limits their ability to devote time to productive activities. Even during the busy periods of harvest and planting, six hours a day are devoted to cooking. This time cannot be viewed as available for productive activities unless labour saving devices become available to reduce the domestic workload. In addition, childcare is generally a secondary activity masked by other domestic activities and may constrain women's ability to increase hours worked outside the home. Policies aimed at increasing women's involvement in agriculture need to take into account their domestic responsibilities because these have a direct impact on the well being of family members, particularly children.

8.9 Conclusions

The purpose of this paper was to investigate what investments small-scale producers make, what factors influence investment and whether they would be captured in the national agricultural database. To this end a survey of 155 households was conducted in two rural communities in the Peruvian highlands in February through March of 1998. The types of investments made by small-scale producers were compared to official statistics. The form used for the 1994 Agricultural Census was the main instrument employed for purposes of comparison because it is the most up-to-date reference available for rural households in Peru.

Overall, the level of investment was small, 82 percent of the households invested less than 1 000 New Soles (US$385) during the previous crop year. The average amount invested was US$266. The distribution of investments in terms of the sums involved follows a similar pattern in the two communities. Nearly 52 percent of all households did not invest at all during the 1996/97 crop year. The majority of the households in Quilcas did not make any investment (70 percent), versus only 31 percent in Pazos.

No major differences in terms of household composition, number of children, educational level of the head of household, or use of crops appear to exist between investor and non-investor families in these two communities. However, female-headed households, particularly in Quilcas were more likely to invest. In addition, Quechua-speaking households were more likely to invest than Spanish-speaking households were.

Factors related to whether a household invested included: possession of more cultivated lands, livestock sales, more savings (chiefly from household or community sources) and higher farm income.

The survey data indicated that households rely on a combination of the households' own funds and contributions or inputs from the community, with little input from external public and private agencies. The importance of community assistance is demonstrated by the fact that during the 1996/97 crop year 45 percent of the investments and improvements made were carried out with community assistance. The construction of infrastructure for public use, in particular, tends to be carried out as a community investment. This includes reforestation, ditches and channels, roads, bridges, nurseries, seedbeds, dipping tanks and training courses. The survey results demonstrate the importance of community organization in gaining access to public assets and in improving agricultural infrastructure.

It was found that the information compiled in the Agricultural Census does not cover assets or infrastructure used in the processing activities involved in producing derived farm or livestock products. While the investment information provided by the Agricultural Census covers the quantities of available agricultural infrastructure, the value of those investments is not indicated. A comparison of the Agricultural Census records on investment variables and those of the survey showed that, on average, 31 percent of the value of the investments made by small-scale producers was registered in the Agricultural Census. This situation gives cause for concern in terms of the formulation of policy recommendations for investment programmes intended for small-scale agriculture. The official statistics would appear to be somewhat unreliable, since they omit the majority of investment needs. In view of these circumstances, it is clear that more specific studies need to be conducted in order to determine the actual requirements of poor farm families.

References

INEI (Institución Nacional de Estadística e Informática). 1994. Censos Nacionales 1993. IX de Población y IV de Vivienda. Lima, INEI, September.

INEI. 1996. Censo Nacional Agropecuario III, 1994, resultados definitivos. Lima, INEI.

Velazco, J. 1998. Estadística descriptiva: Encuesta regional a pequeños productores sobre determinantes de la inversión agropecuaria en pequeñas parcelas. An unpublished report to the Food and Agriculture Organization, May 1998.

Zevallos, E. ed. 1994. *De la costa a la sierra: mujer campesina.* Lima, Stilo Novo y CEDEP.