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Productivity and Efficiency Measurement in Agriculture

Literature Review and Gaps Analysis

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Preface

This literature review and gaps analysis is undertaken in the context of the research line on the measurement of agricultural productivity and efficiency of the Global Strategy to Improve Agricultural and Rural Statistics.

It seeks to define the different concepts and present the main measurement methods for agricultural productivity and efficiency. It does not intend to provide an exhaustive and detailed description of each method and its theoretical grounding. Instead, this review and gaps analysis focuses on the most common ones, identifying the challenges associated with implementation of them, especially with respect to data requirements.

This activity, as with all the other research lines of the Global Strategy, is aimed at improving the capacity of developing countries in the provision of quality statistics on the agricultural and rural sector for which productivity is a significant and policy-relevant domain. In this perspective, the present literature review focuses on the challenges of productivity and efficiency measurement faced by developing countries, which, as many authors have pointed out, have led to missed estimates of overall agricultural productivity and its driving factors. This review relies as much as possible on studies and papers that have focused on developing countries, providing concrete examples of the implementation of productivity and efficiency measurement.

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All remaining errors are of the sole responsibility of the authors of this document.

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1

Introduction and Purpose

Agricultural productivity and efficiency is at the centre of many of the debates, policies and measures concerning the farming sector. The emphasis placed by the Sustainable Development Goals on agricultural productivity underlines the many reasons for which additional research on statistical frameworks for productivity and efficiency targeted to developing countries is necessary. Information on agricultural productivity is related to several of the Sustainable Development Goal indicators, in particular:

- Indicator 2.3.1: Volume of production per labour unit by classes of farming/pastoral/forestry enterprise size;
- Indicator 2.3.2: Average income of small-scale food producers, by sex and indigenous status;
- Indicator 2.4.1: Proportion of agricultural area under productive and sustainable agriculture.

In parallel to global initiatives, such as the 2030 Agenda for Sustainable Development, several countries have introduced policies to improve agricultural productivity, especially in countries where agriculture is a major economic sector and the productivity gap among the primary sector and other industries and services is the widest. Enhancing productivity in agriculture is important because of its effective contribution to poverty reduction through better food security and higher farm incomes.

The central role of agricultural productivity in the economic and social agenda of developing countries was reinforced by the Malabo Declaration of June 2014,[2] which puts agricultural productivity growth at the centre of the objective of Africa to achieve agriculture-led growth and fulfil its targets on food and nutrition security. In the Declaration, it is stated that in order to end hunger in Africa by 2025, at least a doubling of agricultural productivity is needed from current levels.

[2] The Malabo Declaration on Accelerated Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods (26-27 June, 2014).

In this context, proper statistical frameworks are required to monitor progress towards achieving national, regional or global targets on agricultural productivity. Research on the measurement of agricultural productivity is not new and can be traced back to the classical theory of economic growth. More recently, Solow (1957), Diewert (1980), Ball et al. (1997); Ball & Norton (2002), among many others, have made essential contributions towards developing a better understanding, measuring and analysing agricultural productivity. To the best of the authors' knowledge, however, only a small part on this wide body of research specifically addresses the challenges faced by developing countries in collecting the basic data and in implementing the appropriate approaches to compile nationwide indicators of agricultural productivity and efficiency. The weak statistical infrastructure, lack of appropriate data collection protocols and insufficient surveys and censuses in these countries limit the availability and quality of data on agricultural productivity. Among the weaknesses of agricultural statistics in developing countries, Kelly et al. (1996) identified the underestimation of output, yields and labour productivity as the most prominent ones.

In addition to addressing basic data requirements, there is need to better define and measure concepts related to productivity, such as technical and economic efficiency. Productivity measurement has traditionally assumed the inexistence of technical inefficiencies in the production process. Starting with Nishimizu & Page (1982), followed by Fare et al. (1989), the research community has been placing additional emphasis on the decomposition of productivity changes into a technological change component and an efficiency component. This distinction is important. As noted by Grosskopf (1993), if inefficiencies exist and are ignored in the measurement of productivity, productivity growth no longer necessarily tells us about technical change and the policy decisions based on these indicators may be flawed. A better understanding and measurement of efficiency in agriculture is required in the context of lower availability of key resources and production factors, such as land or water in adequate quantity and quality.

Another topic that, to the best of the authors' knowledge, has not been widely researched is the description and quantification of the link between productivity and farm incomes. Indicators measuring the impact of productivity gains on income generation and food security are useful for policy-making and monitoring, especially in developing countries where smallholders and family farms are predominant. In this perspective and given the predominance of labour among the production costs of these farms, adequately measuring the productivity of labour provided by the farm holder and household members and its impact on household incomes should be the priority.

The research line of the Global Strategy on "Measuring agricultural productivity and efficiency" seeks to contribute to the reduction of these methodological and data gaps. To this end, cost-effective data collection and computation methods will be identified and field-tested in selected developing countries. The objective will be to produce operational guidelines and training material to help developing countries produce data and indicators on agricultural productivity and efficiency.

This research starts with a literature review and gaps analysis on agricultural productivity and efficiency. Its first objective is to provide clear definitions of essential concepts, such as agricultural productivity and efficiency, often used as synonyms although they cover different dimensions (section 2). Section 3 reviews the main approaches for measuring the productivity of agricultural inputs and production factors, from the farm-level to sector or economy-wide scales. By doing this, the document also provides some insights on how to properly account for the farm outputs, the numerator of any productivity measure. Section 4 reviews how technical efficiency is defined and measured in the literature, at farm and aggregate levels. Section 5 explains how agricultural productivity and farm incomes can be related and how this relationship can vary depending on the type of holding. Section 6 illustrates some of the methodologies and approaches described in the literature through the example of the United States of America, which, to some extent, can be considered as the gold standard in terms of productivity measurement. Section 7 concludes.

2

Basic Definitions and Concepts

2.1. What is agricultural productivity?

A general definition

"Productivity is commonly defined as a ratio of a volume measure of output to a volume measure of input use" (OECD 2001b). At its most fundamental level, productivity measures the amount produced by a target group (country, industry, sector, farm or almost any target group) given a set of resources and inputs.

Productivity can be measured for a single entity (farm, commodity) or a group of farms, at any geographical scale. The measure should reflect the ultimate purpose for the inquiry. If for example, the purpose is to compare productivity between farms, then measures that are micro-based are required. If the need is to evaluate national agricultural policy at the country level, then macromeasures are required. This same analogy can extend beyond the sector to the national economy. While the desired purpose can vary, the measurement issues associated with deriving the different indicators are the same. However, data requirements may differ depending on the type of indicator: farm-level productivity measurement for one commodity and one input (for example, labour productivity of maize farms) may only require basic information on output quantities and input use, while producing aggregated measures generally requires pricing outputs and inputs.

Similar to most indicators, a single statistic rarely, if ever, tells a complete story to provide policy-makers and analysts with sufficient information to unambiguously prescribe the best policy. For example, a productivity measure for agriculture that is often cited is crop output per land area (commonly referred to as crop yield), with a higher yield corresponding to higher productivity. It quickly becomes apparent that the challenge with this and similar measures rests with how they are interpreted. Continuing with this example, a higher yield may be indicative of improved fertilization practices (use of a better fertilizer and/or more efficient application), land of higher quality allocated to the crop, the use of a better-educated workforce or more efficient use of capital. However, it may also just be explained by basic factors beyond the farmers control, such as the soil conditions and even the weather.

Discussion

Productivity measurement has its origins in the microeconomics "theory of the firm" in which, after simplifying assumptions, it can be shown that inputs can be combined optimally to allocate scarce resources, allowing firms to maximize profits subject to a cost constraint or to minimize costs subject to an output constraint. Both will result with an input allocation that is efficient[3] or optimal. Productivity is studied because, through increased productivity, firms (or industries, or countries) can better allocate scarce resources to other pursuits. It leads to higher national income by virtue of this reallocation, by more efficiently using inputs and by reallocating the "surplus" to other endeavours. Both results stem directly from the analysis of productivity.

In its simplest form, productivity measures describe the relationship between the production of a commodity — good or service — and the inputs used to produce that commodity. It can be the relationship between one or more products and one or more inputs. Either way, all production, sold or not, and all inputs, whether they are paid for, should be correctly valued.

As productivity measures describe how the transformation of inputs into products is affected by efficiency and technological change, it follows that productivity measures are often volume based. However, in some cases, efficiency and technological change may not be factors behind increased productivity. One example would be if production were to double in response to a doubling of output prices caused by an external shock.

Most farms produce multiple commodities with many inputs. While it is technically possible to define multi-product output in terms of physical measure (kilogrammes or joules, for example), it is simpler to convert volumes to monetary values to perform the aggregation. The aggregation of different inputs is also generally done using values. In this case, productivity change is measured by comparing the productivity between two periods using the prices of a fixed reference period. The difference is, therefore, only attributable to quantity or volume changes and not due to price variations.

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[3] For a more complete discussion on technical and economic efficiency, see sections 2.3 and 2.4.

Levels versus growth rates

The need to take into account the multi-output multi-input nature of agricultural activities in productivity measurement explains why indicators focus more on period-to-period changes than on levels, which can be difficult to interpret. Producing estimates of period-to-period changes has the additional advantage of minimizing the effect of the measurement errors affecting level estimates, provided that measurement techniques and sources remain constant. This results in a more accurate estimate of productivity change. However, while change estimates are easier to produce and interpret, these calculations bring in some additional measurement issues related to the choice of proper indices and weighting strategies.

The study of growth rates and levels is not a frequently researched question in literature on productivity, mostly for the reasons presented above. Nonetheless, completing traditional productivity growth measures with information on levels may be relevant for several reasons. First, would be for international comparability purposes. Countries that have already reached high levels of productivity have less room for additional substantial productivity improvements, contrary to countries where agriculture is less capitalized, subsistence-oriented and therefore, where the productivity gap is wide. Comparing productivity growth of these two groups of countries makes little sense without additional information on the levels. Second, levels are more intuitive for single-input (or partial) productivity measures. For example, labour productivity can easily be measured in levels, such as output per number of hours or days worked. Levels can be easily compared across subsectors, regions and countries to provide evidence of differences in input productivity. Some elements on how productivity levels and growth rates can be constructed at different levels of aggregation are given in section 3.1.

Farm versus commodity level

Measuring productivity at the commodity level entails collecting plot or activity-level data on a specific output and on the intermediate inputs and production factors, such as labour, land and capital used in its production.

Measuring productivity at the farm level implies collecting data on all the outputs produced and on the different inputs and production factors used. In principle, as productivity is the ratio of outputs to inputs, the quantification of productivity not only requires a proper assessment of agricultural production for the main crops or activities of the holding but it also required for the minor ones and for by-products, such as hay used for forage or manure for fertilization. The lack of proper accounting for secondary crops or by-products has been identified by Kelly et al. (1996) as one of the major reasons for the underestimation of agricultural productivity in Africa.

Given that most agricultural holdings tend to produce several outputs using many inputs, outputs and inputs generally need to be converted into monetary units for calculating productivity measure, which, in turn, allows for the aggregation of a variety of them into a common measure. This means, however, that proper input and output prices must be available and/or estimated. The presentation of value-based productivity indicators is also needed to compare productivity levels of two different products. Measuring the physical productivity (for example, tonnes/hour) allows comparing the productivity of two farms that are producing the same product, but not for different crops. In the latter case, it is necessary to refer to the monetary productivity, converting the volume produced into a gross output measure (per hour worked, for example).

Differences between agriculture and other sectors in terms of productivity measurements

In many respects, productivity measurement for agriculture mirrors that for other industries. Notwithstanding this, there are several characteristics of the agriculture sector that make it significantly different and, therefore, worthy of special consideration.

In most countries, agriculture is comprised of a large number of small enterprises. These small businesses often use unpaid owner and family-supplied labour. For the productivity analyst, this fact must be accounted for either explicitly as an adjustment or in the interpretative analysis. The linkages between an increase in farm labour productivity and farm family income is not straightforward.

Natural conditions, such as climate patterns or soil characteristics, have a much greater effect on agriculture than on most other industries. This is not a problem in itself, but it does mean that the analyst must exercise a degree of caution when analysing productivity estimates, not only within a country, but also when making international comparisons. It also means that statisticians seek to collect data for certain groups or typologies of farms, often based on the agroclimatic characteristics in which they operate.

Agriculture is also a sector in which a significant volume of inputs can, depending on the farm type, originate from within the sector and even from the farm itself. Feed is produced and fed to livestock. Seeds can be retained for subsequent planting. Labour can be exchanged with other farmers. Beyond this, agriculture outputs are often consumed on the farm, which is a form of income even if no market transaction takes place. Land, a key capital input, varies greatly depending on how arable it is, both across one country and within countries.

None of the foregoing information makes estimating productivity for agriculture impossible, but it does suggest that care needs to be taken when so doing. When collecting or analysing data on agriculture, accounting for these specificities is essential for the analysis to be credible.

2.2. Total factor productivity and partial productivity

Definitions

Multi factor or total factor productivity growth (MFP or TFP) is the change in production not resulting from a change in all or several inputs, which in agriculture is usually land, labour and capital. MFP is, therefore, the difference between production and input changes or what remains after estimating the contribution of inputs to production change (OECD 2001b). This residual (what cannot be attributed to a change in the volume of inputs) is often interpreted as the sum of pure efficiency change, technological change, and measurement errors.[4] MFP is almost exclusively expressed as a variation or as changes because, given its highly aggregated nature, level measures would have little meaning. As the Centre for the Study of Living Standards (CSLS) points out, MFP captures the residual effects of several elements of the production process, such as improvements in technology and organizations, capacity utilization and increasing returns to scale, among other factors. It also embeds errors due to the miss-measurement of inputs and output (de Avillez 2011, p. 16). Productivity measures can also be used to illustrate how well a single input is used to produce products and in the case of labour, this is termed labour productivity.

[4] "Further, in empirical studies, measured MFP growth is not necessarily caused by technological change: other non-technology factors will also be picked up by the residual. Such factors include adjustment costs, scale and cyclical effects, pure changes in efficiency (OECD 2001b) and measurement errors."

This concept is often calculated, but as already shown, it is difficult to interpret. Improved labour productivity can be the result of improved use of labour, but it can also be the result of intensified use of other inputs, such as fertilizer or machinery. Nevertheless, CSLS also argues that "labour productivity is a better tool for understanding improvements in overall living standards" essentially because it is unbounded (de Avillez 2011, p. 29)

Discussion: choosing indices to properly measure productivity changes

As previously stated, productivity measures are always volume based, either expressed in physical quantities, or in constant value terms, implying that values be adjusted for price change. In order to get real or constant dollar measures, time series for outputs and inputs as well as for prices are required, or alternatively required are output and input volume and price indices. Obtaining the correct price or price indices, in turn, adds significantly to the complexity of productivity measurement, most of which is related to matching the correct price (or index) to the product or input. In the case of outputs, the price or index used needs to consider the different characteristics associated with the product, especially the quality characteristics that are associated with the observed price. Using properly constructed price indices has been the focus of much of the research on productivity because series indices are commonly used.

Over the years, the research has suggested using different price indices for deflating outputs and inputs, each with different properties and each yielding different results. Selecting the appropriate one to use is rooted in theory, but essentially the choice focuses on how well the chosen price index accounts for substitution bias. It has been shown by Diewert (1976) and countless others, that superlative indices (those that satisfy certain numeric properties) can account for this bias, but they have the base constraint (assumption) that the industry under study operates under perfect competition and with a certain type of production function. Because of its desirable properties, the Törnqvist index is often used to measure TFP for a number of reasons. First, the Törnqvist index is a discrete approximation of the Divisia index, widely believed to be the best index for measuring economic aggregates because of its capacity to faithfully represent the underlying production function and invariance property.[5] Second, as the Törnqvist index is a superlative index, it can be related to many production or cost functions. In particular, it corresponds exactly to a Translog function. Third, another advantage is that this index is consistent in

[5] As the weights of a Divisia index are being changed continuously, the errors of approximation as the economy moves from one production configuration to another are eliminated.

aggregation: constructing subgroup indices and combining them in an aggregate index yields almost the same result than aggregating all prices and quantities together.

Discussion: the "gross output" versus "value-added" approaches

Either "gross output" or "value added" estimates can be used to calculate productivity. Gross output is generally defined as the value of production while value-added is gross output less intermediate inputs, which is referred to in national accounts parlance as intermediate consumption. The value-added based estimate can be used to measure the returns (net revenue) generated by labour, land and capital, the primary factors of production.

The gross output measure is often used for estimating agriculture productivity so that the significant contribution of intermediate inputs, such as pesticides, fertilizers, plant protection products or seeds, to the sector's productivity growth can be taken into account. It is well known that the improvements to intermediate inputs, such as the ones mentioned, have led to improved production in the agriculture sector. This is the approach followed by the agriculture productivity programme of the United States Agriculture Department (USDA), which is often considered the "gold standard" for agriculture productivity measurement. Section 6 contains a more complete description of the USDA agriculture productivity programme.

The value-added approach is meaningful for understanding profitability and the economic returns from factors of production in agriculture, which is required for measuring the net production of production costs. Value-added is often used to compare the profitability of the agriculture industry with other industries because value added estimates for all industries are generally produced on a consistent basis within a country's system of national accounts.

2.3. Technical efficiency

Agricultural productivity is usually considered to depict the efficiency of the production process, as explained previously in this document. However, as Grosskopf (2002); Nishimizu & Page (1982); Fare et al (1989); and others have argued, this is true only under the assumption that the farm (or firm) is technically efficient, arguably a strong assumption. To understand how these two notions are connected, it is useful to note that agricultural productivity depends on two components: the type and quality of the inputs used in the production process; and how well these inputs are combined. The first component represents the production technology while the second refers to the technical efficiency of the production process.

Productivity improvements are often entirely attributed to efficiency gains, but this is often incorrect. For example, Ludena (2010) estimates that agricultural productivity gains over the period 1961-2007 in Latin America and the Caribbean have been exclusively driven by technological change, while efficiency changes have actually been negative over the period. These approximations arise from the lack of a clear understanding of what is technical efficiency, how it differs from technological change and how it is connected to productivity.

Agricultural policies tend to focus more on fostering productivity through technological change than through better use of the existing technology. However, rebalancing the focus of agricultural policies towards improving efficiency is necessary in the context of limited availability of natural resources, such as land and water, and given the necessity to limit the environmental footprint of agricultural production. Equivalent physical productivity gains and perhaps even larger economic gains may be expected from better use of existing technology than from shifting to new technology. The latter may increase productivity in the short term, but possibly at the expense of higher production and environmental costs. For example, before advising farmers to adopt chemical fertilizers (technological change), traditional fertilization methods involving organic fertilizers and rotations or mixture of crops (technical efficiency) may be promoted as a way to increase physical productivity and improve food security and economic profitability. Technical efficiency is described in detail in the following paragraphs.

Production technology is characterized by the type of inputs and resources available. For a given commodity, many different technologies may exist, reflecting different economic, environmental and agronomic conditions.

The type of inputs and resources that can be used in the production process defines production technology. The production frontier corresponds to the combination of inputs that generate the maximum attainable output. Accordingly, the production frontier is in fact the best practice frontier (Charnes et al. 1978). It differs across countries and regions because of differences in the nature, quality and availability of the inputs, such as soil quality, precipitation levels and qualification of the workforce. For example, rice yields in sub-Saharan Africa will probably never reach yields observed in

South-East Asia because soils, rain patterns and other essential inputs have structurally different characteristics.

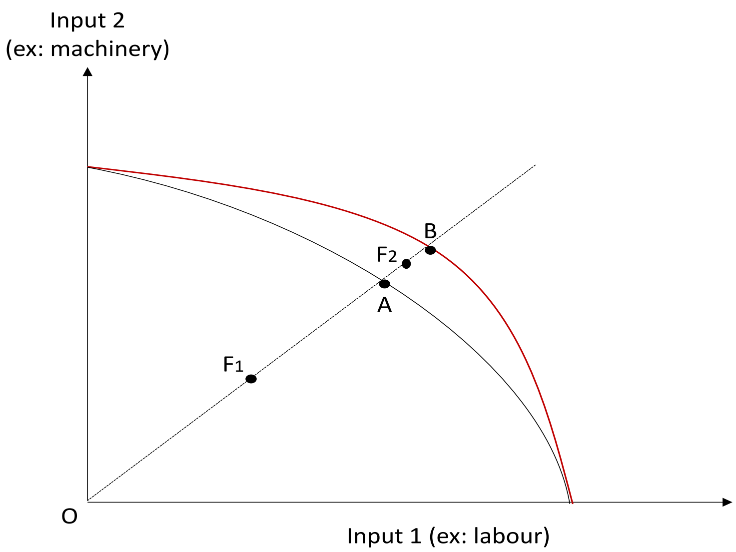
A farm is technically inefficient when it does not produce the maximum level of output that can be expected given the type of available inputs

The production frontier is reached when available inputs are used optimally. A farm (holding) that reaches its production frontier has also reached its maximum level of technical efficiency. More formally, following Odhiambo & Nyangito (2003), an agricultural holding can be considered as technically inefficient when, given its use of inputs, it is not producing the maximum possible output. Equivalently, a holding is technically inefficient when, given its output, it is using more inputs than necessary. The concept of technical efficiency is important because it justifies the existence of differentiated productivity targets, taking into account both the resource and input base (the technology), and the distance to the most efficient practices: a holding can be efficient in the sense that it has reached its own potential maximum production, but less productive than a less efficient farm benefiting from higher quality inputs.

Figure 1, adapted from Ludena (2010), provides a simple illustration of technical efficiency and how it differs from productivity, strictly speaking. For the purposes of this example, the very simple case of an agricultural holding operating with two substitutable inputs, such as labour and machinery, is considered. Any combination of labour and machinery along the black line (point A, for example) corresponds to technical efficiency, in the sense that the farm produces the maximum amount allowed by the technology. The technology is characterized by aspects such as the type of soil, meteorological patterns or the type of capital and labour available. The bisecting line (black line) illustrates the total production or yield reached with the chosen combination of the two inputs.

The farm currently operates at F1, an inefficient level. To reach the efficiency frontier, it needs to better use the inputs at its disposal. Consider now a new technology, characterized by inputs of a better quality, such as richer soils or a better-trained workforce or machinery that is more efficient. These two technologies may be found in different countries or regions, characterized by different resource and input endowments, for example. This production technology is represented in the figure by the red line: for the same amount of inputs, a higher production can be reached. However, the fact that the potential production is higher with this technology does not mean that farms will necessarily be more efficient. For example, a farm may be operating at its efficiency frontier with the black technology, but with a lower yield or production than an inefficient farm F2 benefiting from better technological conditions (red line) and with a yield/production comprised between A and B.

Figure 1. Technical efficiency and productivity: an illustration



The production frontier is a theoretical concept and, as noted by Sadoulet & de Janvry (1995), represents the optimal productivity target and has to be compared to observe productivity to measure the degree of technical efficiency (or inefficiency) at the farm-level. The measurement of efficiency relies on the definition of the production frontier which, given the heterogeneity of conditions and the diversity of environments in which farmers operate, does not have to be unique. It is likely to vary across agroclimatic environments and types of farms (subsistence/family farms vs. commercial holdings) or type of markets targeted (organic or conventional), for example.

2.4. Economic efficiency and competitiveness

Economic efficiency

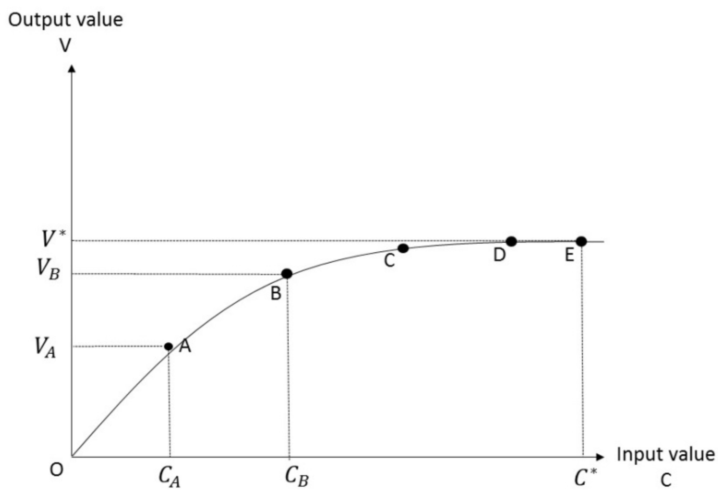
According to Kelly et al. (1996), an agricultural holding reaches economic efficiency when the marginal value of the inputs[6] is equal to their respective unit costs: if the marginal value is higher, the holding can earn higher profits by

[6] The marginal value of an input is the additional output value generated by the use of one additional unit of input.

producing more, thereby becoming more efficient. If the marginal value is lower, the farm should reduce its production to increase its profits.

Figure 2, adapted from the G20 Meeting of Agricultural Chief Scientists White Paper (Fuglie et al. 2016) illustrates the process of convergence towards economic efficiency. The y-axis represents the output value and the x-axis the inputs costs. The black line indicates how inputs are transformed into outputs: the points situated on this line indicate that the agricultural holding is operating at the highest potential yield or production given the type and quality of inputs used, that is, it is technically efficient. Assuming fixed input and output prices, any increase in production value for technically efficient holdings (from V_A to V_B, for example) is due to an increase in the quantity of input used (from C_A to C_B).

Figure 2 – Economic efficiency: an illustration



The ratio between output value and input value measures the amount of value generated by one monetary unit of input: in other the words, the economic return per monetary unit spent. This indicator is also known as unit margins or profits. The figure illustrates that the additional return generated by an increase in use of inputs declines as more inputs are being used: the additional value created by moving from A to B is higher than for the change from B to C and so on until reaching E. After E, any additional quantity of input used does not translate into higher output, meaning that the additional return is 0. E can, therefore, be understood as the point at which the farm is economically efficient: before E, there is scope to increase the overall profitability by using more inputs; after E, any additional use of input will result in lower profits. This is due to the existence of declining returns to scale in agriculture, which is a widely known and observed phenomenon resulting from the fact that yields and production are bounded by physical constraints. Yields can rise as far as more inputs are used, but up to a certain point, after which, the use of additional inputs will have no impact on yields and only result in higher costs.

In practice, a technically efficient farm can be economically inefficient.[7] It is especially true in developing countries where markets are often thin or inexistent, inputs are constrained (unavailable or difficult to access) and transaction costs are high. For example, a farm may need to use more of a certain type of input to reach prescribed technical efficiency targets, but it may not have an economic interest to do so given the current market conditions (very high input cost, for example). Information on the marginal productivity of key inputs as well as on their costs of acquisition is useful in understanding the production constraints that farmers face and how they might react to certain stimuli that are regulatory or economic in nature.

Moreover, and perhaps more importantly, the concept of economic efficiency is largely irrelevant for certain groups of farms, especially farms in which their main priority is to satisfy the livelihoods of their related household(s). For those holdings, producing more food may not be an objective if self-sufficiency is ensured, even if by doing so, they would achieve higher economic returns. Conversely, agricultural households that are not producing enough to satisfy their needs cannot envisage reducing output to maximize economic efficiency. This does not mean that the analysis of farms through the prism of economic efficiency should be theoretically limited to commercial farms. First, because having information on the underlying economic profitability of subsistence farms is useful to understand how profitable farming may be compared to other potential activities. Second, because the dividing line between commercial and subsistence farming is not clear-cut: farms may run activities that serve different purposes, such as producing food for the household (for example, sorghum and millet in sub-Saharan Africa), generating cash revenue (such as cotton and sugar crops) or both (maize and cassava). Furthermore, once the basic needs of the household are satisfied, subsistence farms may essentially turn to profit-generating activities.

[7] The reciprocal, though, is not true: an economically efficient farm has to also be technically efficient.

Competitiveness

An additional distinction that needs to be made is between economic efficiency and competitiveness. The former is an absolute measure of the economic performance of the farm whereas the latter compares this performance to that of their competitors. In other words, a farm can be economically inefficient but competitive because other farms are even less efficient. Reciprocally, an economically efficient farm is not necessarily competitive if all the other farms are also economically efficient. Competitiveness also goes beyond the price/cost performance and extends to the features attached to the output or to the producing firm (or sector, country), such as quality attributes, both true and perceived. For example, a firm can have comparatively high unit costs but may benefit from a high "non-price" competitiveness, which allows it to sell its products at a higher price.

A more precise definition is given by Porter (1990), who differentiates competitiveness according to the geographical scale:

- At the local level, "competitiveness is the ability to provide products and services more effectively and efficiently than relevant competitors and to generate, at the same time, returns on investment for stakeholders";
- At national or regional level, "competitiveness is the ability of enterprises to achieve sustainable success against their competitors in other countries, regions or clusters" (Porter, 1990).

Competitiveness is most often measured using economic indicators, such as gross or net margins (often per unit of land), and comparing the performance of farms (or farming systems) based on these measures. Competitiveness and productivity are closely related: higher productivity can lead to a greater competitiveness of the enterprise (or sector) because more is produced out of the same amount of resources. This means that, with all things being held equal, the cost of production per unit of output is lower, and that margins per unit of output are higher. Productivity is a necessary precondition for competitiveness, but not a sufficient condition. Indeed, a multitude of factors affecting the competitiveness of an enterprise has been identified in the literature. Competitiveness is the result of a combination of factors, both national and international:

- Nationally, resource endowments, technology, productivity, product features, fiscal and monetary management and finally the trade policy are seen to be the most important factors that determine the competitiveness of an industry and/or business. Productivity is, therefore, seen as one of the national (domestic) determinants of competitiveness;

- Internationally, the most important factors are exchange rates, international market conditions, the cost of international transport and the preferences and settings between different countries (Porter, 1990).

3

Measuring Productivity in Agriculture

3.1. Measuring agricultural output

Concepts

As productivity is the volume measure of production (output) divided by the volume measures of inputs,[8] it is important to define what is meant by production or output.

To keep measures of productivity consistent and aligned with economic theory, production should measure the total output of a specific production process that combines intermediate inputs and factors of production to create a product. It is counted if the product is sold for domestic final consumption, including home consumption by the agricultural household, for export or added to inventories.

Practices for the treatment of products that are used as an intermediate input for other agriculture production can vary, but whichever method is chosen, it must ensure that the concept is consistent on both the output and input sides of the farm accounting balance sheets.

This can be illustrated by way of an example. Suppose a farmer sells grain to a feed processing mill that, in turn, sells processed feed to a livestock farmer. Most statistical systems would count the sale from the farm to the mill as a sale from agriculture (part of output) and the purchase of the feed from the mill as an intermediate input. Now consider feed grown on the farm that is used for the farmer's own livestock. It is common and correct not to count own account feed as an output if agriculture productivity is being measured. This holds except if there is an interest to measure crop productivity or livestock productivity separately. Under that situation, it would be necessary to value gross commodity flows.

[8] The term "volume" means that outputs and inputs are either measured in physical terms or, most frequently, in value terms, but using the prices referring to a fixed reference period. This allows interpreting period-to-period changes as changes in volume.

Following the above example, output can be measured as the sum of sales plus own-consumption plus change in inventories. It is also appropriate to measure livestock inventory change in weight gain and not just by the change in the number of heads so that the compositional change in the livestock herd can be better accounted for. As this approach is very data intensive, the number of head method is mostly used. Using auxiliary information and parameters can derive weight estimates. Crop production is measured net of harvesting losses and, if possible, net of other on-farm post-harvest losses, to capture the amount that is actually available for use or to be sold. Reducing farm losses would directly translate into higher productivity, as it would lead to higher output with no additional input cost.

In principle, agricultural output should not include on-farm transformed production if the expenses associated with those outputs can also be excluded. Output of transformed products is generally attributed to manufacturing industries. Countries may, however, opt to include transformed products for items that require limited transformation, such as milk products, in sectors in which most of the farm revenue come from selling or consuming these goods, or if the expenses cannot be clearly separated (the production technologies of the raw and processed product are joint). The output considered should only refer to on-farm processing, and any output generated by off-farm processing should be systematically excluded.

Prices used to value output are market prices at the farm gate. To measure the underlying productivity, output prices should be net of any subsidies received or taxes paid. These prices are also referred to as basic prices. When output is recorded at basic prices, any tax (subsidy) on the product actually payable on the output is treated as if it were paid (received) by the purchaser directly to the government instead of being an integral part of the price paid to the producer (OECD, 2001b). The information on subsidies is, however, useful for conducting a cost of production and profitability analysis. Own-consumption should be valued at the price the farmer would have received had the output been sold rather than consumed, or in other words, the opportunity cost).

Measurement issues

Farming systems in developing countries tend to be fairly diversified. Often, they combine crops and livestock activities and cash crops with subsistence activities. Proper accounting of the output of the farm, including secondary crops, by-products and unsold produce, is a prerequisite for obtaining an adequate measurement of productivity.

The common practice of mixed cropping in developing countries where several crops are simultaneously grown on the same parcel of land adds complexity to the measurement of output. Kelly et al. (2016) found that the most important problem associated with the measurement of productivity in developing countries, and particularly in sub-Saharan Africa, is the underestimation of output and yields because secondary crops and by-products are not properly estimated. An illustration of this is provided by Hopkins and Berry (1994), who estimated that in Niger, returns to labour (labour productivity expressed in monetary units) were 20 per cent lower when only the principal crop was accounted for, as compared to when the output is measured for both the principal and secondary crops.

The case of horticultural crops is another example of lack of proper accounting of the crop output. Because of the small area generally occupied by those crops as compared to cereal or typical cash crops, the corresponding output is typically not accounted for. This is especially the case when the farmers are just starting to diversify into such products as fruits and vegetables. The potential high value and relative importance of revenue generated by horticultural products make it necessary to include them in the measurement of farm output (Kelly et al. 1996).

Another source of underestimation of output is the lack of accounting for crops that serve as inputs to other production processes: if an output is used as input in another enterprise (the case of hay used for animal feed, for example), it should be accounted for as an output for the crop enterprise, otherwise, the measurement of agricultural output, as well as the measures of profitability and productivity at the micro level are biased (Kelly et al. 1996).

3.2. Quality-adjusted inputs in agricultural productivity measurement

Agricultural productivity is dependent on the quality of the inputs and how well those inputs are integrated in the production process. For example, land productivity highly depends on the location of the land and its physical characteristics. This is the same for labour as the quality of the work force differs across, for example worker types or subsectors.

For comparative purposes, the quality of the input must be taken into account in the data collection and appropriate adjustments need to be made after the data are collected. This means that data on input use need to be collected for different types of inputs or quality classes. For example, family labour, occasional workers and permanent workers should be differentiated in the data collection process. Because workers with different skills have different levels of productivity, using the same wages for workers with different qualification levels results in biased estimates of labour productivity. The same applies to fertilizers or to any other input or production factor that has varying characteristics. With regard to fertilizers, this input varies in terms of the dosage of active ingredients to pesticides, which may be more or less effective. One kilogramme of fertilizer applied in 2000 is not comparable to one kilogramme applied in 2015, because of two factors: the introduction of new and more effective products; and fertilizer demand may have shifted towards other segments of the market. This change in composition should be reflected in differentiated input prices.

To address the issue of compositional or quality change, sophisticated frameworks for input quality adjustments have been developed. The United States Department of Agriculture-Economic Research Service (USDA-ERS), for example, estimates quality-adjusted wages based on data of hours worked and wages per hour cross-classified by different labour categories (the following section on labour productivity provides additional details). For land productivity, land prices or rents can be imputed using hedonic regressions that take into account some of the differences in quality attributes, such as soil type, moisture, soil acidity and salinity. Quality-adjusted prices for other inputs can be constructed using similar techniques.

Taking into account input quality is crucial for attaining accurate TFP estimates, but this requires the availability of detailed and accurate datasets on input quantities, values and prices for different quality classes. This requirement leads to increased data collection costs and a higher response burden.

3.3. Land productivity

Definition

The productivity of the land measures the amount of output generated by a given amount of land. It is mostly applicable in the context of cropping activities, but it can also be extended to livestock production, in certain cases, as shown below.

There are several productivity measures that can be calculated: a broad measure is the ratio between the value of all agriculture products (crops and livestock) and the total land used in agriculture. Other land productivity measures can be calculated by dividing crop production by the amount of planted land, expressed in an area unit, such as hectares or acres. When expressed in terms of physical output, such as tonnes of maize, land productivity corresponds to crop yields. When expressed in monetary terms, land productivity is more often referred to as returns to land.

Land productivity = Volume of output / Planted Area[9]

Planted area is used instead of other area concepts, such as harvested area, because of the interest to measure the effective yield or land productivity rather than a theoretical or biological yield. The use of inputs prior to the harvest is made on the sown/planted area (such as fertilizer applications) and not in reference to the harvested area, which at the pre-harvest phase is usually unknown. The difference between harvested and planted area may also reflect the efficiency and relevance of the farming practices, in addition to exogenous factors, such as climate-related events, which should be reflected in the productivity indicator. Using harvested area instead of planted area tends to lead to overestimations of yields and returns to land because this area includes the most productive segments of the parcel. In general, it is best to use planted area for a monocropping system and cultivated area, including fallow land, for mixed cropping systems.

Agricultural production used for the calculation of productivity should include the production of the crops grown on the same land during the reference period whether it is one cropping season or one year. This is important because, in practice, farmers often grow more than one crop on the same plot over a year; they may grow a mixture of crops on the same plot at the same time or rotate the crops grown on the plot over the season. Kelly et al. (1996) stressed that one of the reasons behind the tendency to underestimate output and yields in developing countries is the lack of accounting of crops grown in mixture or in sequence and the lack of appraisal of by-products, which may be sold, consumed by the household or used in the production of other products. It is, therefore, essential that all crops are included in the measurement of productivity, especially in developing regions where these practices are common.

[9] Planted area in this context includes permanent crops and the pasture.

Measurement issues

- Units

As with other inputs, land productivity can be expressed in many units. Given that the land may be used to grow many different crops, a physical unit, such as tonnes, may not be the best choice. Putting a monetary value on their respective output is often needed to aggregate the output of different crops.

- Land quality

Productivity measurement should take into account as much as possible soil and land quality differences by collecting data on the soil/land characteristics and their related aspects, especially land prices and rents. For example, differences in the quality of land across states and regions in the United States are reflected by calculating relative prices of land from hedonic regression results. Ball et al. (2008) applies a hedonic approach to measure quality-adjusted land prices assuming land price is a function of characteristics of land quality variables, such as soil acidity, salinity and hydric stress. The output derived from the land use depends on the soil and land characteristics. USDA uses a database that gathers information on those characteristics in different states and regions from the "World Soil Resources Office". This method, even though it is accurate, requires a large amount of data that are not necessarily available in developing countries.

Indeed, land/soil characteristics and yields may not always be linked, as intuition would suggest, limiting the generalized use of models and other data imputation tools. For example, Vesterby & Krupa (1993) have shown that soils of poor physical quality can sometimes produce very high yields.

In addition, land values do not necessarily reflect environmental aspects of soil quality. In developing countries, for example, land prices may be more closely related to the existence of irrigation systems on the farm. Usually, irrigation infrastructure and equipment are measured in the capital input. When measuring land productivity, it is important to at least identify the percentage of land that is irrigated in the total land available.

- Land productivity and livestock production

Land productivity can also be calculated in relation to livestock activities to the extent that the land is directly devoted to pasture/grazing or to the cultivation of crops destined to feed the animals, such as hay or silage crops. Land productivity cannot be calculated for livestock systems fully based on stall-feeding management.

Land productivity for livestock measures livestock production in terms of output per unit of land. The type of livestock product (output) of the enterprise has to be well identified (whether it is, for example, meat, milk, eggs or live animals). The land productivity is then the volume of the livestock product (tonnes of beef, for example) divided by the unit of land used for livestock, especially the land that is devoted to pastures, hay and silage crops.

In mixed livestock and cropping systems, the productivity of land used for cultivation can increase with the presence of animals because animals transform nutrients from legumes and pastures and put them back in the soil in the form of manure and urine, which are organic inputs. In an agricultural system based only on livestock raising, feed has to be bought from the market and the waste produced by animals cannot be easily eliminated.

- Natural capital and productivity measurement

Productivity measurement should take into account as much as possible the existence and characteristics of the natural capital. Natural capital is the natural environment in which the production takes place and comprises such factors as the quality of the land in terms of natural minerals and fossils composition and weather patterns (rainfall, temperature and sunlight, among others). Understanding the role of natural capital for agriculture and their interactions is essential in determining the environmental sustainability of farming activities, or their capacity to obtain sufficient yields in the long term without generating any type of negative externalities to the environment where the production occurs. The depletion of natural capital may potentially lead to short-term economic growth or an increase in yields, but this would be at the expense of future growth if the revenues that are generated from the short-term growth are not reinvested to maintain or increase the capital base, physical and natural (Schreyer et al. 2015).

Data on farms should be geo-referenced, to enable the superposing of information on soils and land coming from other datasets. The same applies to data on weather patterns. In addition, basic information on the type of soils should also be collected. Information on practices affecting the environment, such as manure management or pest control, can also be sought. Collecting and presenting data for different types of agro ecological zones, the definition of which may be more or less sophisticated depending on data availability, is necessary for making assessments and comparisons of yields, revenue or input use between different typologies of natural environments and production conditions.

Data requirements for land productivity measurement

Output data:

- Crop production, including secondary/minor crops and by-products, in quantities and values;
- Number of animals by species;
- Livestock production by product in quantities and values.

Input Data:

- The total area of land planted for each crop;
- The average annual per unit cost of land;
- Total area of land available for cropping, namely the sum of cultivated land for all crops and fallow land;
- The share of land used for pasture;
- Management system for livestock.

In addition, information on the environment and production conditions, as described above, should be made available.

3.4. Labour productivity

Definition

Labour productivity in agriculture measures the number of units of output(s) produced per unit of labour used in the process of production. It is a partial productivity indicator that is calculated by dividing the quantity of output by the total units of labour used:

Labour productivity = Volume of output / Units of labour used

There are many ways to assess the quantity of labour input: the number of workers active on the holding; the number of time units (such as hours, days and months) worked or full-time equivalent units if an average number of hours per working day can be determined according to specific country standards.

OECD (2001) recommends that labour input be measured using the number of hours effectively worked. Using the number of hours corrects for the difference between seasonal and non-seasonal workers and the different working regimes (part-time versus full-time). This allows better comparisons across production systems, regions and countries, as the number of workers or of days per worker may not indicate the labour input effectively used on the farm.

However, the change in the number of hours reported does not always reflect the use of capital, the quality of the workforce and technology (Shumway et al. 2015). USDA-ERS suggests that productivity measurements capture the different types of labour working in the sector because labour input differs based on the categories of workers. It is recommended that distinctions be made between different ages of workers, family labour and hired labour and men and women. Distinctions can also be made between part-time and full-time workers. A distinction should also made between the different educational levels, because the quality of one hour provided by a worker is often dependant on his skills and capacities.

In that regard, the example of USDA labour accounts is informative. For the farm sector, labour accounts incorporate the demographic cross-classification of the agricultural labour force developed by Jorgenson, Gallop & Fraumeni (1987). Matrices of hours worked and compensation per hour have been developed for workers cross-classified by sex, age, education and employment class (employee versus self-employed and unpaid family workers). These characteristics are detailed in table 1.

Table 1: Characteristics of labour input for productivity measurement

	Sex	Age	Education	Employment class
(1)	Male	14-15 years	1-8 years grade school	Wage/salary worker
(2)	Female	16-17 years	1-3 years high school	Self-employed/unpaid family worker
(3)		18-24 years	4 years high school	
(4)		25-34 years	1-3 years college	
(5)		35-44 years	4 years college	
(6)		45-54 years	more than 4 years college	
(7)		55-64 years		
(8)		65 years and over		
(9)				
(10)				

Source: USDA-ERS

In addition, ERS has developed a set of similarly formatted but otherwise demographically distinct matrices of labour input and labour compensation by state. This is accomplished using the Bi-proportional MatrixBalancing (RAS) procedure popularized by Jorgenson, Gollop, & Fraumeni (1987), which combines the aggregate farm sector matrices with state-specific demographic information available from the decennial Census of Population (U.S. Department of Commerce). The result is a complete state-by-year panel dataset of annual hours worked and hourly compensation matrices with cells cross-classified by sex, age, education, and employment class and with each matrix controlled to the USDA hours-worked and compensation totals, respectively. Indices of labour input are constructed for each state and the aggregate farm sector using the demographically cross-classified hours and compensation data. Labour hours having higher marginal productivity (wages) are given higher weights in forming the index of labour input than are hours having lower marginal productivities. Doing so explicitly adjusts the indices of labour input for "quality" change in labour hours, as originally defined by Jorgenson & Griliches (1967).

Measurements issues

The accuracy of the labour productivity estimate depends on the quality of the data in the numerator and the denominator. As mentioned earlier, it is recommended to measure labour in as much detail as resources and collection constraints permit, with the ideal being to capture the number of hours or days per person over a specific period of time, and not as an aggregate, such as the number of persons employed by the holding. The latter does not inform about the actual time spent on agricultural activities: for example, full-time, part-time or seasonal workers do not work the same number of hours per year. Until recently, many national and international datasets on labour only provided the number of workers employed by the agricultural sector (Kelly et al. 1996). However, improvements have been made and data on effective labour input in agriculture are becoming more readily available. Examples are data on the average weekly hours actually worked by agricultural employees disaggregated by sex provided by the International Labour Organization.[10] Combined with information on the number of persons employed in the agricultural sector, it is possible to estimate the labour input in the agricultural sector, measure labour productivity and carry out cross-country comparisons. However, data gaps for several developing countries, especially in Africa and parts of Asia, remain important.

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[10] See www.ilo.org/ilostat.

Labour productivity is often linked to other factors, such as land and capital. For instance, as noted by Kelly et al. (1996), farmers in countries where labour is scarce and land is abundant tend to adopt production systems that provide high labour productivity. Capital also plays a major role in labour productivity. In the past 50 years, labour productivity in agriculture has increased because of the growth in crop yields globally. Roudart & Mazoyer (2006) show that in some regions of industrialized and emerging countries, yields have been reaching ten tonnes of cereals or cereal equivalent per hectare, close to the maximum attainable level. This yield increase is mainly the result of using genetically improved seeds, with high yield potential, along with an increase in chemical fertilizers and pesticides use and, in some cases, the intensification of irrigation. Improvements in labour productivity are also often related to increased mechanization because machines that are more efficient require less labour to cultivate a larger area. Therefore, the disparity in estimated labour productivity across countries and regions can be partially explained by the wider use of machinery in developed countries in comparison to developing countries. This illustrates the limitations of partial productivity indicators in accounting for structural changes in farm inputs and their composition, which modify the respective contribution of each input to farm productivity. Relationships between labour productivity and other inputs are further described in section 5.2. in connection with farm incomes.

Data requirements

Labour quality differs across countries, type of activities, region and many other dimensions. High-skilled workers produce a different output than low-skilled workers, which yields very different effects on production (OECD 2001). Taking into account differences in labour quality is important when labour input is expressed in value terms (wage): failure to differentiate labour types in the valuation of labour input, for example, using wages for low-skilled workers to value labour provided by high-skilled labour results in biased estimates of labour costs and returns to labour. This issue becomes mute when using a physical measure of labour productivity: if labour quality is higher in one country and if the number of hours worked are correctly measured, this is reflected in higher labour productivity for this country (expressed in tonnes per hour worked, for example).

The increased precision and level of detail in disaggregating different labour categories, such as age, gender and education, leads to higher data collection costs, possible response bias and a greater response burden.

To summarize, the proper measurement of labour input for productivity measurement requires a specific type of information, in particular on the following:

- Number of workers per category of workers, including unpaid family labour;
- Characteristics of workers (table 1);
- Number of hours worked per agricultural product/activity;
- Net wage (cash and in kind payment) per category of worker, including an estimation of imputed wages for unpaid labour;
- Value of any type of compensation or benefits paid for or provided by the employer, either in cash or in kind, such as pension contributions or social security.

3.5. Capital productivity

Definition

Capital productivity measures the contribution to production of the capital employed in the production process. Capital is usually defined as an input owned by the farm that provides services over several years. When measuring capital, most productivity measures only focus on farm buildings, machinery and equipment. Hired and owner-supplied labour is often considered to be a form of capital (human), but it is commonly measured as labour input (OECD 2001). Tree stock and orchards, as well as livestock can also represent a capital stock when they result from an investment (purchase of animals or the establishment of a new plantation, for example) that leads to a regular flow of revenue or service (revenue from the selling of fruits or milk or service provided by animal traction, for example). However, given the specificity of these assets, the fact that the measurement is particularly complex (especially in developing countries) and the relatively few references on the subject, this section focuses on traditional assets, such as machinery, equipment and buildings. Ball & Harper (1990) can be consulted for a specific discussion on livestock as capital assets.

Capital productivity is computed using the following formula:

Capital productivity = Volume of output / Volume of capital input

Capital input is determined by estimating the service flows stemming from the capital employed. To estimate capital service, it is necessary to first estimate the stock of productive capital used for each asset type, then determine rental prices and finally estimate capital service flows.

Capital stock

The capital stock consists of the value of all the fixed assets, such as machinery, equipment, buildings and other structures, used by the farm, that provide inputs in the form of capital services into processes of production. The capital stock can also be viewed as the cumulative value of the past capital investments made.

To measure capital stock, two approaches are generally used:

- **Approach 1 - perpetual inventory method (PIM)**: it involves adding to the previous year's stock the estimate of the current year's new investment while simultaneously ageing the productive capital by one year as it is moved forward, a process known as capital depreciation. Capital depreciation is most often estimated by asset type with farm buildings and structures depreciated over a much longer time horizon than farm machinery, reflecting actual service lives. The perpetual inventory method can, therefore, be formalized as the following: $\mathbf{K_t = I_t + (1 - \mu)K_{t-1}}$; where K_t is the current year's capital stock, I_t current year's investment, and μ the replacement rate or depreciation factor.

- **Approach 2- current inventory method (CIM):** it is based on a count and valuation, sometimes adjusted for the estimated average age of capital goods, of the set of capital goods being used on a farm. Although the perpetual inventory method is mostly used to estimate capital stock, it requires an important set of data, unlike the current inventory method.

The choice of the method (PIM or CIM) depends on the data collected and available. If macrolevel total factor productivity is measured, then using the PIM method for capital is a first best approach, unlike its application in micromeasures.

Capital investment is depreciated by using a formula mostly because robust market prices for age-type capital goods generally do not exist. Various methods can be used to depreciate capital. Each one depicts the service life of a capital asset. The straight-line method assumes that a capital asset will provide constant service for a set number of years. The hyperbolic formula infers that the service falls off less when the asset is new and more when it is old. For all of the methods, a somewhat arbitrary service life for the asset must be selected.

The *OECD Manual on Capital Stock Measurement* gives detailed examples of the capital measurements methods, which are summarized below.

Table 2: Capital measurement methods of the OECD Capital Manual

<table>
<tr><th rowspan="3"></th><th colspan="6">Type of age-efficiency or age-price profile</th></tr>
<tr><td colspan="2">One-hoss-hay (O) or hyperbolic (H)</td><td colspan="2">Straight-line</td><td colspan="2">Geometric</td></tr>
<tr><td>User cost weights</td><td>Market price as weight</td><td>User cost weights</td><td>Market price as weight</td><td>User cost weights</td><td>Market price as weight</td></tr>
<tr><td>Fixed-weight index number</td><td></td><td>Typical “gross stock” measure in OECD countries (O)
The Statistics Canada’ net capital stock measure with hyperbolic depreciation profile</td><td></td><td>Typical “net” capital stock measure in OECD countries</td><td colspan="2">The Statistics Canada MFP capital input measure</td></tr>
<tr><td>Flexible weight index number
(for example, Fisher, Törnqvist indices)</td><td>The U.S. Bureau of Labour Statistics’ Capital services measure (H)
Australian Bureau of Statistics’ capital service measure (H)</td><td>The Australian Bureau of Statistics net capital stock measure (age-price profile based on hyperbolic age-efficiency profile)</td><td></td><td></td><td>Jorgenson (1989) [11] measure of capital services</td><td>The U.S. Bureau of Economic Analysis Fixed Reprod ucible
Tangible Wealth measure</td></tr>
</table>

Source: OECD (2001b).

[11] Jorgenson, D., 1989. Productivity and Economic Growth. Ernst R. Berndt and Jack E. Triplett (eds.), Fifty Years of Economic Measurement, University of Chicago Press.

Rental prices

After the capital stock is determined, the next step is to place a value on the capital that was used in the year. This value is most often referred to as rental prices, given that capital is often rented. and rental values tend to be more easily observed than actual asset prices. In addition, rental prices include depreciation rates of capital goods.

In the case of an existing rental market (for agricultural machinery, for example) the price of the capital service is measured as its rental price. However, rental markets are thin or inexistent for many capital goods, especially in developing countries. In this case, their rental price can be imputed based on an opportunity cost of the capital, or more commonly defined as users cost of capital. Most countries use the opportunity cost concept from the producer's (decision-maker) perspective by imputing rental values using a rate of return that the producer would likely receive if the current value of the productive capital were to be invested in the next best alternative.

An alternative to estimate rental values when actual rates are unavailable is to infer a rental value using the price of the asset, the income and property tax rates (Lysko 1995).

Finally, the current year's estimate of the capital must be deflated to constant prices if it is to be used for productivity measurement. This involves selecting a proper deflator and index form for the deflation, neither being trivial.

Capital services

Capital service measure the service(s) that can be provided by a fixed asset, such as a farm building, for example.

If the flows of capital services are not directly observable, which is generally the case, they can be estimated as a proportion of the capital stock. The capital service flow is calculated as the rental rate multiplied by the capital stock.

$$Capital\ service\ =\ Rental\ price\ *\ Capital\ stock$$

Data requirements for capital productivity measurement

Data required to measure capital stocks depend on the type of productivity measure that needs to be computed. Some of the main variables and parameters to collect are the following:

- Asset stocks, types and prices;
- Rates of replacement or depreciation rates;
- A time series of investment expenditures on the asset;
- Retirement pattern: in order to find out whether the asset has been withdrawn from service, information on the retirement pattern must be available. This information is empirical and rather complex to determine. For simplification, it is recommended to choose a distribution around the average service life of an asset;
- Age-efficiency pattern.

3.6. Productivity of intermediate inputs

Intermediate inputs are goods and services that are transformed or entirely used in the production process during an accounting period or agricultural season. They constitute what is also called intermediate consumption. In agriculture, intermediate inputs cover purchases made by farmers for raw and auxiliary materials that are used as inputs for the different agricultural enterprises. These inputs include animal feed, energy, fuel, oil and lubricants, seeds, fertilizers and soil improvers, plant protection, veterinary services, repairs and maintenance, among others.

As intermediate inputs are of a very different nature, they must be added up using a common unit, usually a monetary unit. The intermediate inputs are generally valued at the price effectively paid by the farmer, which may include subsidies and taxes. The identification and quantification of subsidies and taxes is also recommended, as it is a useful source of information for assessing the importance and impacts of these incentives for farmers.

To measure the productivity of intermediate inputs, the numerator of the productivity ratio should be the gross agricultural output, which is comprised of final products and intermediate (agricultural) products used for agricultural production. When value-added or net output is used as the numerator, the effect of intermediate consumption is already taken into account.

3.7. Aggregation of productivity indicators

3.7.1. Aggregation across outputs

Most, if not all, farms produce multiple commodities with many inputs. A common unit for the output should, therefore, be chosen in order to carry out the aggregations, such as monetary value, calories and commodity-equivalent (wheat-equivalents, for example). The different options are discussed below:

Price-based

Putting a monetary value on the respective output allows aggregating the output of different crops and products. This measure is useful if prices used for the valuation properly reflect market conditions. For products that are rarely marketed, finding representative prices may be difficult. It is important that the choice of prices is appropriate and that the valuation be implemented systematically and consistently across farms and time. If one currency unit is chosen as a basis to carry out international comparisons, distortions may be created by the existence of overvalued exchange rates or changes in exchange rate policy (Kelly et al. 1996).

Commodity equivalents

This option is relevant only for food products. Major commodities, such as wheat or maize, can be used as a basis for the aggregation. The output of the other crops is converted to the reference crop using, for example, the calorie intensity of the reference crop as a basis for conversion. This removes the effect of prices and exchange rate policies to obtain a pure physical productivity effect. Kelly et al. (1996) recommends using commodity equivalents to compute productivity indices as a complement to typical value-based indexes.

Calorie equivalent

This option is relevant only for food products. Le Cotty & Dorin (2012), among others, proposed to use calories as the unit to convert the different agricultural outputs (livestock and crops, among others). This allows aggregation across outputs of different types, including crops and livestock products, for example. On that basis, Dorin (2012) provided an estimate of the amount of plant food calories produced per cultivated hectare in the world between 2005 and 2007 that illustrates the strong variations across regions: from 7,700 kcal per ha per day in Oceania to 29,800 kcal per ha per day in Asia, for example.

3.7.2. Aggregation across farms

Aggregating total productivity across farms is not necessarily complex, but the units and the scope must be the same across farms. More specifically, different cases can be distinguished:

Single output and input

The productivity estimate for a group of farms is simply given by the sum on outputs, such as tonnes of millet, and the sum of input, such as total hours worked on millet parcels during the cropping season, or, equivalently, by the input-weighted average of farm-level productivity indicators. An alternative is to estimate productivity using a simple, equally weighted, average of farm-level productivity indicators. The result provided by the weighted average approach reflects the distribution of the farms by size: a significant productivity increase of a few very large producers, for example, leads to an increase of the average productivity. The simple average approach, on the contrary, is not sensitive to farm size distribution.

For this synthetic productivity measure to make sense, it is important that the product considered is the same across farms and similar quality attributes, such as size/weight or moisture content, for example. The output for this product has to be measured in the same way across farms. The same is true for the input considered.

Multiple outputs – single input

If the objective is to measure and aggregate farm-level productivity, namely covering several or all the outputs produced by the farm, it is important to cover the outputs extensively and be consistent across farms: outputs should include the major crops, agricultural commodities or livestock products, as well as secondary and minor crops and any by-products. Failure to do so results in an underestimation of output and, consequently, an underestimation of productivity. As multiple outputs are covered, they should be aggregated into a single output measure using a common unit, such as the ones described in section 3.2.1. The aggregate productivity estimate for the group of farms can be computed either by using: (a) the input-weighted average of farm-level productivity; or (b) the simple average.

Multiple outputs and inputs

If, additionally, productivity is measured in reference to several inputs to produce a TFP or MFP-type of indicator, the scope in terms of the inputs covered should be the same across farms. Inputs also must be aggregated, generally by converting them to monetary units using a proper price. The aggregated productivity indicators can be computed using either weighted or simple average approach. If inputs are converted to values for aggregation, which is typically the case, the weighting variable is the input costs or cost of production if all farm inputs are included.

3.7.3. Aggregations in time

Requirements on the data collection method

The basic requirement for conducting meaningful time series comparisons is that the underlying basic data on outputs, inputs and prices are collected using the same methodology for the different data collection rounds. The aggregation and computation routines used for the different productivity indicators also have to be consistent. For example, if value weights referring to a certain set of inputs for a specific reference period are used in year n to compile a measure of MFP, the same weighting system and reference period has to be used for the computations in year n+1.

For comparisons across time to be meaningful, the sample of farms for which the data are to be collected and indicators compiled must have certain characteristics. One situation is when data are collected from a panel of farms, namely the same holdings are followed at different points in time. The data, therefore, refer to the same sample and the variations in productivity indicators are definitely the result of variations in the drivers of productivity (inputs, outputs) and not in changes in the characteristics of the sample. Attrition in the panel (the fact that some of the holdings leave the sample) can be compensated by adding new holdings with similar characteristics than the missing ones in order to obtain a balanced panel. Productivity indicators, partial or total, in levels (physical or in value terms) or in indices/changes, can be analysed through time for each holding individually or for the sample as a whole (or part of it). While panel-data are by construction appropriate for time comparisons, a sample that is used year after year may not reflect changes in the composition of the agricultural sector. This may be an issue in countries where the agricultural sector is changing rapidly in terms of product mix, farm practices and structure, which is the case in many developing countries. Resampling or changing the characteristics of the panel may be needed to maintain the relevance of the statistics and indicators.

As an alternative to panels, which are costly to maintain and may have certain limitations, new samples are often drawn for each new survey round. In this case, individual comparisons are no longer meaningful because holdings are generally different. However, to the extent that the samples have similar characteristics in terms of size and stratification, the analysis and comparisons in time of average productivity, for the whole sample or only parts of it (for example, for farms growing certain crops or farms above a certain size) can be made. The groups of farms for the productivity comparisons have to be chosen in accordance with the characteristics of each sample in terms of representativeness. For example, if the samples are representative of the farms of the non-commercial sector, comparisons can be made for this group. On the contrary, if the sample has not been stratified according to sample size, for example, the comparison of the evolution of productivity by farm size risks to be flawed.

Analysis of absolute productivity (levels)

Absolute levels of productivity can be compared across time for individual holdings (only if holdings belong to a balanced panel) or for groups of holdings, for typical surveys, which are based on a new sample for each round. As an illustration, consider the indicator of labour productivity, or returns to labour, for a given holding i: $P_i^t = {V_i^t}/{L_i^t}$, where V_i^t is the monetary value of all the outputs produced by i during time t and L_i^t the number of hours worked on the holding i during the reference period t by labour units L. If the survey is based on a panel, P_i^t can be directly compared to P_i^{t+1}, because the holdings compared are the same ones.

When data from different samples are compared, averages /aggregations for relevant groups have to be compiled first. Consider for example: $P^t = {\sum_i V_i^t}/{\sum_i L_i^t}$, the measure of labour productivity for the whole sample or any relevant subset of it. P^t and P^{t+1}, although computed from different samples, can be compared under the conditions on the sample discussed above.

Analysis of productivity growth: indices

Analysis of productivity is often done using indices and/or measures of changes. This is because level indicators are not easy to interpret when they refer to multiple outputs and inputs. Aggregated productivity indices provide a way to describe the evolution through time of productivity in a meaningful and consistent way. Additionally, the use of measures of change helps to deal with measurement errors in level estimates to the extent that those errors are stable through time. The determination and construction of indices to measure productivity change are complex, are dependent on assumptions that if not satisfied, the results may be seen as being questionable and have a bearing on their interpretation. This subject has been well researched. It is not an objective in this document to discuss index theory in detail. Interested reader should refer to OECD (2001b, pp. 83-92), for a comprehensive review of index number formulation in the context of productivity measurement.

To illustrate the process of construction of indexes and their interpretation, consider the simple example of the comparison of returns to labour between two years, t and $t+1$. The labour productivity index for year t is given by: $I^t = {P^t}/{P^{t_0}}$, where P^{t_0} is the absolute productivity measured in a given fixed base year t_0. Yet, ${I^{t+1}}/{I^{t1}} - 1 = {P^{t+1}}/{P^t} - 1$ measures productivity growth between t and t+1. Without imposing additional assumptions on the indices, the interpretation of this measure of growth is limited. Indeed, measured in this way, productivity growth can be the result of several factors, which cannot be isolated:

- Changes in farm-level physical productivity;
- Changes in the nominal prices of the different outputs produced by the holdings;
- Changes in the share of each holding with respect to the labour input.

To isolate the effect of physical productivity changes to improve the interpretability of measures of productivity growth, choices have to be made on the period of reference that is to be used for the prices and other variables used in the computation of the indices. Usually, the reference period is fixed and typical quantity indices, such as Laspeyres, Paasche or Fisher are relevant in that setting. Choosing a fixed reference period has its shortcomings, especially because it usually indicates that a fixed production or cost structure is to be assessed, which may be problematic if the index refers to a period that is far from the reference period for the weights. After a fixed weights index has been selected, the next step is to choose the year/period that will be used as a reference for the weights, either the beginning of the period (Laspeyres), the current period (Paasche) or a combination of the two (Fisher). The first option is clearly s less demanding in terms of data, because information on the weights has to be obtained only for the beginning of the period.

As the measure of productivity covers more outputs and more inputs, the complexity of the weighting system increases and the data requirements become more important because, in addition to the data on quantities, more information on prices for the base year/period has to be collected or estimated for outputs and inputs. Inevitably, measurement errors and estimation-related uncertainties also increase with the number of outputs and inputs included in the productivity indicator. This limits the confidence that may be placed in highly aggregated measures of productivity growth and renders its interpretation delicate and inspired authors, such as Cornwall (1987), to consider TFP "as a measure of our ignorance".

4

Measuring Technical Efficiency in Agriculture

4.1. Introduction

Several methods can be used to quantify technical efficiency. All of them broadly follow the same logic: identifying the share of productivity growth resulting from efficiency changes through the measurement of the distance between observed productivity and a theoretical, optimal or average productivity. Based on figure 1, measuring technical efficiency entails determining the distance between F1 and A, a technically efficient input-output combination. In practice, the ratio OF1/OA is the measure of technical efficiency or, equivalently, OA/OF is a measure of technical inefficiency.

The methods to measure technical efficiency differ essentially on the way this distance is defined and estimated and whether auxiliary information is used. Most of these methods can provide farm-level estimates of technical efficiency. Traditionally, measurement methods are classified based on whether they rely on assumptions on the functional form of the production frontier: the ones that rely on those assumptions are considered to be "parametric" while the ones that do not rely on the assumptions are considered to be "non-parametric". For example, Malmquist-type approaches using Data Envelopment Analysis (DEA) are non-parametric, while approaches based on the econometric estimation of a production function are parametric. Although these methods rely on different computation methods and assumptions, it is interesting to note that the results are often not significantly different from each other. For example, Neff et al. (1993) and Sharma et al. (1997) found that estimates derived from DEA are not statistically different from other frontier estimation methods. This finding may put into perspective theoretical debates over the appropriate measurement methods, which is presented succinctly below and contribute to putting additional emphasis on the quality and completeness of the basic data on which these methods are based.

4.2. Measuring and decomposing productivity growth using Malmquist indices

The Malmquist productivity indices constitute the theoretical basis for decomposing productivity growth into technological changes and efficiency changes. This methodology, in its non-parametric version, was first applied by Färe et al. (1989)[12] to measure the productivity of Swedish hospitals. The method's key advantage is that it isolates the respective contributions of technological and efficiency changes to productivity growth. Other measures, such as the Törnqvist approach of ratios of output and input indices, do not explicitly take into account efficiency.

The gist of the Malmquist decomposition is provided below and the formalization of it is given in box 2. Grosskopf (2002) provides a more detailed, formal accessible presentation.[13]

This framework is grounded on the assumption of the existence of an unobservable optimal production technology, or production frontier, which is defined as the maximal amount of output that can be produced out of a given amount of input. The Malmquist productivity index is based on the distance between observed farm-level combinations of inputs and outputs and the unobservable production frontier.

The production frontier and the input-output combinations vary from period to period. The change in productivity between two periods (old and new) can, therefore, be the result of:

- The degree to which observations (input-output combinations) have moved closer to the frontier, evaluated with the old technology;
- The degree to which observations have moved closer to the frontier, evaluated with the new technology.

As there is no reason theoretically to give more importance to one effect over the other, the Malmquist measure of productivity is the geometric mean of these two ratios; it gives equal weighting to each effect.

.[12] A parametric version of the decomposition of the Malmquist productivity index was first proposed by Nishimozu & Page (1982). Färe et al. (1989) followed up on this approach, but implemented it using a non-parametric method.
[13] See http://people.oregonstate.edu/~grosskos/odense01d.pdf .

This index can be easily decomposed into the product of two terms, one of them measures efficiency changes while the other captures technological change. Box 2 provides the formal derivation of the Malmquist productivity index and its decomposition.

Box 1 The Malmquist productivity index and its decomposition

The presentation of Fried et al. (2008) is used here, with slight adaptations and simplifications. $\mathbf{x}$ is the set of inputs that can be used by a farm to produce a set of outputs $\mathbf{y}$. The technology T is defined as the set of all possible input-output combinations: $\mathrm{T} = \{(\mathbf{x}, \mathbf{y}) \colon \mathbf{x} \text{ can produce } \mathbf{y}\}$. The output set $\mathrm{P}(\mathbf{x})$ is the set of all technologically possible outputs: $\mathrm{P}(\mathbf{x}) = \{\boldsymbol{y} \colon (\mathbf{x}, \mathbf{y}) \in \mathrm{T}\}$. The output distance function $\mathrm{D}(\mathbf{x}, \mathbf{y})$ with respect to T is the maximum possible expansion of output ($\mathbf{y}/\varphi$, $\mathbf{1}/\varphi$ being the expansion coefficient) allowed by the technology. Formally: $\mathrm{D}(\mathbf{x}, \mathbf{y}) = \min\{\varphi \colon \mathbf{y}/\varphi \in \mathrm{P}(\mathbf{x})\}$. The first Malmquist productivity index (M) compares the distance of the output-input combinations of periods t and $t+1$, relative to the technology of period t: $\mathrm{M}_t = \mathrm{D}_t(\mathbf{x}, \mathbf{y})_{t+1} / \mathrm{D}_t(\mathbf{x}, \mathbf{y})_t$. The second compares the same observations by using period $t+1$ technology as a reference: $\mathrm{M}_{t+1} = \mathrm{D}_{t+1}(\mathbf{x}, \mathbf{y})_{t+1} / \mathrm{D}_{t+1}(\mathbf{x}, \mathbf{y})_t$. The final Malmquist productivity index is conventionally defined as the geometric mean of these two indices. $\mathrm{M}_{t,t+1} = \sqrt{\mathrm{M}_t . \mathrm{M}_{t+1}}$. One possible decomposition is:

$$\mathrm{M}_{t,t+1} = \frac{\mathrm{D}_{t+1}(\mathbf{x}, \mathbf{y})_{t+1}}{\mathrm{D}_t(\mathbf{x}, \mathbf{y})_t} \cdot \left[\frac{\mathrm{D}_t(\mathbf{x}, \mathbf{y})_t}{\mathrm{D}_{t+1}(\mathbf{x}, \mathbf{y})_t} \cdot \frac{\mathrm{D}_t(\mathbf{x}, \mathbf{y})_{t+1}}{\mathrm{D}_{t+1}(\mathbf{x}, \mathbf{y})_{t+1}}\right]^{1/2}$$

The first term measures the contribution of technical efficiency to productivity changes: it compares the distance of the input-output pairs to the benchmark technology of the corresponding period. The term in brackets captures the contribution of technological change: it compares the distances for the same observations but under different technologies (t and $\mathrm{t} + 1$).

The Malmquist decomposition provides a theoretical framework for measuring productivity growth and quantifying its main drivers. The implementation of it in practice requires the specification and estimation of the production frontier and distance functions.[14] Approximations of Malmquist productivity measures are often applied using superlative index numbers or DEA, two non-parametric approaches. Orea (2002) proposed an econometric (parametric) approach, which is not presented here because it is not often used in practice. Fried et al. (2008) on pages 68-71, give a good introduction to this method.

[14] Under restrictive assumptions such as constant returns to scale, that are rather inconsistent in the context of agriculture, Caves et al. (1982) show that the Malmquist productivity index does not require estimation of distance functions because it is equivalent to the ratio between a Törnqvist output index and a Törnqvist input index.

4.3. Superlative index numbers

Superlative index numbers provide, under certain conditions, an approximation of the "true" productivity growth defined by the Malmquist approach. The measurement of productivity growth using Fisher and Törnquist indices, two superlative indices, is the oldest and most used approach by statistical agencies around the world to measure productivity growth. This approach uses data on quantities and prices to compute productivity index numbers without attempting to construct the production technology, contrary to DEA or other methods that are described in this paper.

The Fisher (respectively, Törnquist) productivity index is the ratio of the Fisher (respectively, Törnquist) output and input quantity indices. The basic definitions and formulae of these indices are not presented in paper, however, they are given in Fried et al. (2008). Diewert (1992) proved that under certain conditions, the Fisher and Törnquist productivity indices are strictly equal to the Malmquist index, namely that there is no approximation at all. One of these conditions, however, is very restrictive: it requires that production levels in both periods be efficient for both outputs and inputs markets. In other words, although these indices can provide good approximations of Malmquist productivity and, in some cases, an equivalent measure, they are not able to decompose productivity growth in its different components. They are, therefore, of little or no use for the measurement of technical efficiency.

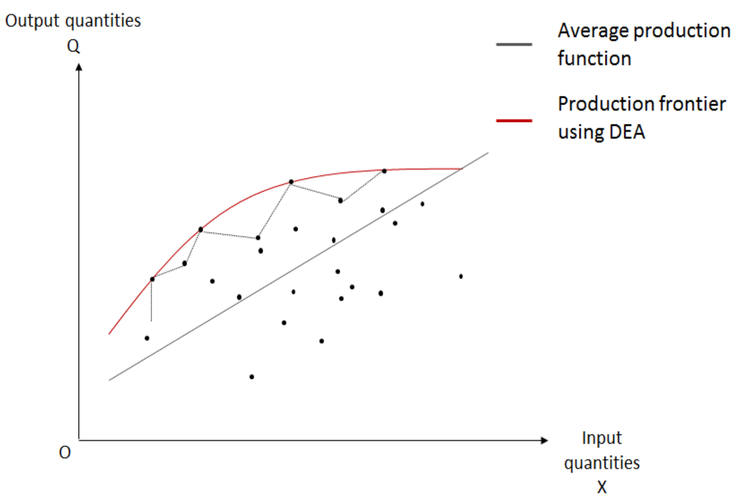
In addition, superlative indices require data on prices for all outputs and inputs, as values are used to weight quantity changes. These prices are missing in many cases, especially in countries where statistical information is sparse and irregular. Under those conditions, the quality of the resulting productivity estimates may be considered diminished.

These limitations (impossibility to measure technical inefficiencies) and high data requirements have led to the development of approaches, such as DEA, which allow for the measurement of technical inefficiencies and are less demanding in terms of data.

4.4. Data Envelopment Analysis

This method entails determining a frontier that envelops all the input-output data, with observations lying on the frontier defined as technically efficient, while those below are seen as being technically inefficient. DEA determines this frontier by constructing a virtual (or composite) producer with the highest possible efficiency, using farm-level data on outputs and inputs and without imposing any restrictions on the production technology. The frontier is constructed by identifying iteratively the "best". In this sense, as noted by Charnes et al. (1978), who introduced and generalized this approach, this frontier can be understood as a best practice frontier. The frontier "envelops" the observations, when an average production function passes through the centre of the data. This is illustrated in f3, which is adapted from Arnade (1994).

Figure 3 – Construction of the production frontier using Data Envelopment Analysis



To compute the distances used in the Malmquist productivity measure, observations on the input-output combinations need to be available for different time periods. The efficiency level of each producer for a given period is simply computed by taking the distance from a particular observation to the frontier.

The main advantages of using DEA to productivity growth and its determinants are the following:

- It does not require any assumption on the production technology of the farm/sector;
- It can be used at any level of aggregation: from the farm-level to sector, country or even international levels;
- It allows for multiple outputs and inputs;
- It only requires data on quantities produced and inputs used. It does not require data on prices or weights. This is a key advantage over other methods, given the high proportion of outputs and inputs in the

developing world that are not marketed and, therefore, have no market price.

Mathematically, the iterative process of construction of the production frontier with DEA can be presented as a problem of linear optimization. The result is an optimal set of input-output combinations for each product, describing the production technology of a virtual or composite producer with the highest possible efficiency. The general formalization is presented in box 3. Arnade (1994) can be consulted for more details on the underlying formalization and for empirical examples. An interesting and recent application to the agricultural sector can be found in Perdomo and Mendieta (2007), who measured and analysed the technical efficiency of the Colombian coffee sector.

Box 2 Determining the best-practice frontier using Data Envelopment Analysis

The mathematical problem of DEA is to find a set of weights that maximize the output expansion of the producer under consideration, under the constraint that the producer cannot be more efficient than the "best" producer. Mathematically, the programme for a given producer 0 can be formulated as follows:

$$Max_{\varphi,\theta}\varphi$$

Subject to the constraints: $x_{l0} \geq \sum_{i=1}^{I} \theta_i \, x_{li} \;\; \forall l = 1, \dots, N \; inputs$ (C1)

$\varphi y_{k0} \leq \sum_{i=1}^{I} \theta_i \, y_{ki} \; \forall k = 1, \dots, M \; outputs$ (C2)

$\theta_i \geq 0 \quad \forall i = 1, \dots, I \; producers$ (C3)

The weighted sums of inputs and outputs represent a composite producer that performs better than the producer under consideration: the composite producer uses less inputs (C1) and has an output that is always higher to what the producer under analysis might potentially expect (C2).

The maximum expansion factor φ measures the distance between the observations and the "best" producer. This programme is solved for each producer in the sample, allowing the construction of the best practice frontier. If input-output observations are available for several periods, the different Malmquist distances can be computed, allowing a breakdown of productivity growth in its drivers, technical efficiency and technological change.

If the production system is highly dominated by one input and/or if the interest of the analyst is to characterize the efficiency with respect to one input, say labour, the optimization system becomes simpler as $l = 1$.

There are drawbacks to using Data Envelopment Analysis methods:

- Being a non-parametric technique, it is difficult to undertake hypothesis testing and measure the precision of the resulting indicator;
- Being based on an optimization procedure, the results may be unstable (small changes in values may lead to significant changes in the results) and the procedure may be computationally intensive, especially when a large number of producers and input-output combinations are involved.

4.5. Parametric approaches to efficiency measurement

Parametric approaches to efficiency measurement explicitly take into account the existence of production inefficiencies, similarly to DEA, but, in addition, they make certain assumptions on the nature of the best practice technology. Sadoulet & de Janvry (1995) is followed for this paper. They proposed to distinguish three families of parametric methods: engineering approaches; average production functions; and stochastic production frontiers. These methods capture technical efficiencies and, provided that the required data are available for multiple periods, can also be used to estimate and decompose productivity growth as per the framework of Malmquist.

Engineering approach

Herdt & Mandac (1981) proposed to use data from experimental plots in farmers' fields to estimate both the production frontier, in the sense of the best production function, and the actual production technology used. The parameters of the production functions, calibrated using the data collected from the experimental plots, include the following:

- A standard set of technical coefficients associated with inputs, such as fertilizers, seeds or pesticides ($\boldsymbol{x}$);
- Variables that characterize the farm's environment, such as soil quality or climate characteristics ($\boldsymbol{env}$);
- A set of variables that indicate if the production practices or technology is applied by the farm ($\boldsymbol{pract}$).

The measure of inefficiency is computed as the difference between the production (q) estimated when production practices are set to best practices ($\boldsymbol{pract} = best$) and the production estimated with practices set to actual practices ($\boldsymbol{pract} = actual$):

$$IE = q_{best} - q_{act}$$

With $q_{best} = f(\boldsymbol{x}, \boldsymbol{env}, \boldsymbol{pract} = best)$ and $q_{act} = f(\boldsymbol{x}, \boldsymbol{env}, \boldsymbol{pract} = actual)$

Several conditions need to be fulfilled in order for this method to yield usable results:

- The experimental plots selected need to allow sufficiently high variability in the technology used (input type, mix and quality) and in the production conditions, such as agroclimatic zones;
- Complete, detailed and accurate data on input use and production conditions need to be collected;
- The best practices have to be well identified and characterized, given their variability across zones, products and other dimensions. An example of best practice is the use of mechanical irrigation in zones where rainfall is low or uncertain and for crops that are known to be water intensive, such as maize.

This approach can be used to evaluate both technical and economic efficiency. In the first case, physical quantities are used to evaluate production and inputs whereas in the second case monetary values are considered.

Among the main limitations and risks associated with this approach, the following can be identified:

- It assumes a specific shape of the production function $f(.)$, usually linear, for the farms considered. In doing so, it considerably restricts the set of possible production technologies;
- Being a deterministic approach, confidence intervals and error estimates cannot usually be computed. If experimental plots are selected based on a random procedure, the error associated to sampling can however be measured;
- The results can be considered as representative only if the full range of production conditions and production technologies are taken into account, which requires a sufficiently large sample of farms and plots.

Average production function

This method is used to compare efficiency between prespecified categories of farms, assumed to use the same production technology. It is very straightforward and involves estimating standard production relationships linking inputs to outputs, including farm-category effects in the form of dummy or categorical variables. Farms can be categorized according to their size, type (subsistence versus. commercial, for example) or any other criteria deemed relevant. Yotopoulos & Lau (1973) provided an application of this approach to test efficiency differences between small and large farms with a Cobb-Douglas specification of the production function.

The production or profit functions are usually estimated using econometric techniques applied to cross-sectional or panel data at the plot or farm-level. The results depend on the chosen shape of the production function (specification error), as with any other parametric approach. Using flexible functional forms, such as the Translog transformation, can mitigate this possible bias.

Another limitation of this method is that, contrary to DEA and also to the engineering and the stochastic frontier approaches (described below), it does not produce farm-specific efficiency scores. The method only allows for comparisons across groups of farms, classified according to predetermined criteria, such as size or type.

Stochastic frontier analysis

This approach entails measuring efficiency based on an econometric estimation of a production function that explicitly includes an inefficiency component. This method assumes a specific type of production function. However, its account of inefficiency is more explicit and general than other parametric methods, such as the engineering approach, which requires predetermined best practices and the average production method that compares technical efficiency only between predetermined groups of farms (large or small, for example).

Since the publication of the work of Aignier, Lovell & Schmidt (1977) and Meeusen & van den Broeck (1977), production frontier analysis has been widely used to estimate technical efficiency for many agricultural commodities in several regions and countries and under different production systems and agroclimatic regions. Among the recent references, the work of Adedeji et al. (2013) stands out. They used a stochastic production frontier to estimate the technical efficiency of poultry egg production in Ogbomoso metropolis

(Nigeria). Also of note, Kouyate (2016)[15] used this methodology to estimate the effects of irrigation systems on the technical efficiency of rice growers in Mali (box 4).

Readers interested in the theoretical grounding and the details regarding the estimation of stochastic production frontiers may refer to Aignier, Lovell & Schmidt (1977). The backbone of this approach is provided in this report. Stochastic frontier analysis is based on the standard production function approach, which relates the quantity of output (or yield) of a given farm i (q_i) to the quantity of inputs used ($\boldsymbol{x}_i$) through the production technology $f(.)$. The difference between this method and other parametric methods is the inclusion of a random error-term and an individual inefficiency term:

$$q_i = f(\boldsymbol{x_i}).\exp(v_i - u_i)$$

The inclusion of a random error term takes into account that, although the production function is assumed correct on average, random shocks may lead to differences between the observed production and the theoretical output based on the production technology. v_i is generally assumed to be the realization of a symmetric random variable with mean 0.

The existence of an inefficiency component is formalized by defining u_i as a non-negative variable, implying that the observed output will always be equal or lower than the technically efficient output. In the case of absence of inefficiencies ($u_i = 0$), the model becomes a simple production function that assumes technical efficiency.

Within this framework, the measure of technical inefficiency is the ratio between the output assuming technical efficiency and the technically inefficient output:

$$IE_i = \frac{f(\boldsymbol{x_i}).\exp(v_i)}{f(\boldsymbol{x_i}).\exp(v_i - u_i)} = \exp(u_i)$$

[15] Unpublished master's thesis. For details contact: kouyate.88@gmail.com or franck.cachia@fao.org.

To estimate technical efficiency (or inefficiency), two additional assumptions are needed:

- On the shape of the production function $f(.)$, namely how inputs are transformed into outputs, the most common approach is to use a Cobb-Douglas function or its generalization, the Translog function, which allows for crossed effects between different inputs.

- On the modelling of the inefficiency term u_i, it is generally assumed that inefficiency is a linear function of a set of explanatory factors ($\boldsymbol{z_i}$), such as agroclimatic conditions, irrigation management, input management (such as the use of improved versus traditional seeds) and individual characteristics related to the farm holder and farm workers, such as education level, sex and, age, which may influence the way farm operations are run.

The final econometric relationship to be estimated can be written as follows:

$$\log(q_i) = \log\big(f(\boldsymbol{x_i})\big) - g(\boldsymbol{z_i}) \ + v_i$$

Where $f(.)$ can be Cobb-Douglas or Translog and $g(.)$ a linear function of $\boldsymbol{z_i}$, the set of factors assumed to explain inefficiency.

This relationship can be estimated using standard single-equation techniques, such as Ordinary (or Generalized) Least Squares or Maximum Likelihood Estimation. The estimation can be performed on cross-sectional data, such as typical farm or plot-level survey data, and on panel data. In the latter case, the presence of individual and time variability allows for a more accurate estimation of the parameters of the production frontier equation.

Box 3: Measuring and explaining technical efficiency of rice growers in Mali

The objective of this study is to investigate the effects of different irrigation modes on the technical efficiency of rice growers in Mali.

The study is based on farm-level data from the 2013/14 agricultural survey, conducted by the statistical unit of the Ministry of Agriculture of Mali. From this survey, 552 rice-producing holdings (737 parcels) have been identified in the regions of Mopti, Segou and Tombouctou. The survey provides sufficient information to characterize the holdings and the households, including aspects related to access to markets for outputs and inputs. Plot-specific data concern the type and quantity of inputs used, yields as well as information on the type of irrigation system (different systems may be used on different plots).

Stochastic frontier analysis is used to measure the effect of irrigation systems (and other factors) on technical efficiency of rice producers in the three regions. Preliminary statistical tests based on likelihood ratios show that: (a) the Translog specification provides a better representation of the production technology than the Cobb-Douglas; and (b) the production technology is affected by inefficiencies.

The results need to be taken with caution, as for any study based on farm-level data, as they are prone to all sorts of errors, and rely on modelling assumptions. One of the findings of this study is the confirmation that irrigation through gravitation and water pumping increases technical efficiency. The opposite effect is found for systems based on controlled submersion. Indeed, plots using gravitation or pumping are usually better drained. The fact that farmers using gravitation are usually enrolled in local water management boards, through which they benefit from modern installations and technical assistance, may also play a role. Below is an excerpt of the results.

Dependent variable: logarithm of rice yields		
Variable	Coefficient	Significance level
Translog production function $log f(.)$		
Fertilizer	0.16	***
Labour	-0.03	*
Technical inefficiency model $g(.)$		
Irrigation. by gravitation	-0.70	***
Irrigation. by controlled submersion	0.64	***
Use of chemical fertilizers	-0.14	***

5

Agricultural Productivity and Farm Incomes

5.1. Productivity and farm incomes

As a means to achieve the second Sustainable Development Goal (SDG) -- on ending hunger and malnutrition; target 2.3 specifically aims to “double, by 2030, the agricultural productivity and the incomes of small-scale food producers …”. The perceived link between incomes and agricultural productivity is made explicit, and in particular with respect to smallholders.[16] The World Bank has also noted the role of agricultural growth in reducing poverty, estimating that the agricultural sector is about two to four times more effective in raising incomes among the poorest compared to other sectors.[17]

Pursuing these goals implies that there be a common understanding of what farm income is before addressing its linkages with productivity. While farm economists have long agreed that no single definition of farm income can be applied satisfactorily for all circumstances (Jones & Durand, 1954), it is true that a large number of variants can be used to meet specific needs.

These variants are usually grouped according to whether they include imputed revenues (income in kind for unsold and home-consumed produce) or costs (for example, unpaid family labour). *The Handbook on Agricultural Cost of Production Statistics* (Global Strategy, 2016) gives several examples of income indicators used by countries based on different classifications of input costs (see for example pages 15-19 and 89-90). Among the many definitions of farm incomes, the following are of specific interest to this study on productivity and incomes:

Returns over cash costs: the value of the outputs produced by the farm minus the value of the purchased inputs. The outputs of the farm are valued, even if the production is not actually sold on the market, but is instead consumed by

[16] The concept of smallholder may need to be defined, at least for operational purposes related to the Sustainable Development Goal indicator framework. Many definitions can be found in the literature, based on criteria, such as farm size, farm incomes or the predominance of subsistence activities. To date, no agreed-upon definition at the international level has emerged.
[17] See www.worldbank.org/en/topic/agriculture/overview.

the farmer's household or used on the holding. This first measure of income is similar to the concept of net cash income provided by Jones & Durand (1954). In a family farm, returns over cash costs adequately represent the income available to the household at the end of the cropping/agricultural season. Unsold produce consumed by the household can be considered as potential income because it could have been sold on the market. Another way to express this idea is that own-consumption liberates the household from having to purchase an equivalent amount of food on the market.

<u>Returns over cash and non-cash costs</u>: in theory, each year, the holder needs to set aside for consumption or other use, a certain amount of output. The value of this output is used later to replace the farm capital at the end of its life. In farm accounting as in general business accounting, these amounts generally correspond to depreciation costs. After deducting this amount from the previous indicator, returns over cash and non-cash costs or net operating income are obtained. This is referred in the terminology used by Jones & Durand (1954). Depreciation costs are obviously higher for farms on that own large amounts of capital. Family farms in developing countries are usually small farms (in terms of acreage) and have little capital. In addition, the equipment and machinery they use are often rented or shared and used significantly beyond their theoretical useful life. Under these conditions, depreciation costs can be neglected and the analysis of incomes can be based on net cash income (or returns over cash costs).

Based on these two measures of farm income, several indicators can be constructed to assess the income generated by each of the main inputs of the farm, such as return on labour, return on capital or return on land. This section discusses the relationship between agricultural productivity and farm incomes, starting with labour productivity, which is often the predominant input for most holdings of the developing world. This section tries to ascertain to what extent productivity and incomes are linked and how the nature of this relationship can vary depending on the type of holding.

5.2. Labour productivity and farm incomes

Labour productivity is defined in section 3 as the volume of output(s) generated by one unit of labour.

An increase in labour productivity suggests that any given quantity of labour generates higher output or, conversely, that the same level of output can be obtained from a lower quantity of labour input. Under certain conditions, it also means that a higher level of output can be reached within the same cost. In other words, higher labour productivity can generate higher farm income, as measured by the income indicators defined above.

The magnitude of the positive relationship between labour productivity and farm incomes depends on certain conditions. One of those conditions is the timing of the change in labour input, in terms of quantity and quality, during the cropping season. The magnitude of seasonal labour constraints, in terms of quantity and quality, affect farm profits and incomes differently. For example, Kelly et al. (1996) indicated, based on findings from surveys made in Niger, the impact on farm profits from the use of additional and/or more efficient labour would be twice as high during the weeding period, usually considered to be the peak season for grains, than during the slack season (all other periods). Using a common variable to represent family and non-family labour during the entire cropping season, a widely used practice, would, therefore, not take into account the seasonal labour constraints faced by farmers and fail to adequately measure their effects on profits and incomes. The authors also noted that the implication for data collection and productivity analysis was that data needed to be collected at different levels of aggregation and different points in time.

The source of the growth in labour productivity can also affect the link between productivity and incomes, as explained below.

<u>Improvements in the skills set of the workforce</u>: If the growth in labour productivity comes from employing a better-skilled workforce at the expense of low-skilled workers, the labour costs in this situation will likely increase because more experienced or better-skilled workers usually earn higher wages than low-skilled ones. Under this condition, higher labour productivity leads to higher farm incomes only if the rise in output value is not accompanied by the higher labour costs. This depends on (a) the wage differential between different categories of workers; and (b) the location of the farm in the marginal revenue curve. As illustrated in figure 2, if the farm is at the beginning of the curve, far from the efficiency point, small changes in the technology used, such as the employment of a higher proportion of skilled workers, will lead to large increases in output quantities. Therefore, increases in labour productivity, even if they result in higher costs, will likely translate into higher incomes. On the other hand, if the farm is operating close to its efficiency level, increases in output will not compensate for the potential cost increases. Arguably, most of the farm holdings in the developing world, especially the smaller ones, fall within the first category: small changes in how farm operations are performed, such as how and when the application of fertilizer and/or plant protection

products is carried out, are likely to lead to significant improvements in output and income.

With respect to data collection and analytical requirements, this underlines the importance attached to the following:

- Collecting data on labour for different categories of workers, both on input quantities and wages. This is needed to properly measure production costs and compare them with output in order to assess returns to labour and farm incomes;
- Adequately measuring technical and economic efficiency levels for different farming systems, because this helps in assessing the direction and magnitude of the impact of productivity changes on farm incomes.

Increase in the productivity of family/household labour:

Farm labour supplied to the farm by family/household members is often not remunerated in the form of wages and salaries. An increase in the productivity of family labour results in higher output at no additional monetary cost and an increase in the net cash farm income. It makes no difference if the farm produce is actually sold or consumed by household members because higher output equates to higher incomes.

Capital-driven labour productivity growth: The literature review has already addressed, in part, the relationship between the different types of farm inputs, such as capital and labour, and how a change in the productivity of one input may be partly or entirely the result of changes in the characteristics and/or productivity of the other inputs. With regard to capital and labour productivity, it can be shown that the harvest may be completed more rapidly when using a more efficient harvester. This involves that less labour is required to complete the work. The change in the characteristics of the capital (harvester) will directly lead to an increase in labour productivity (assuming that the operation of the harvester does not require hiring a higher-skilled worker). It also results in lower operation costs, such as fuel expenses and other costs associated with the use of the machine.

This type of capital-driven labour productivity increase, therefore, likely results in an increase in net cash income, or returns over cash costs, as defined above. However, the purchase of more efficient capital generally comes at higher costs. The depreciation costs, or amounts that have to be set aside by the farmer in the view of replacing its capital before it becomes obsolete, will also be higher. As a result, non-cash costs will increase and the net operating income, may be higher or lower depending on whether the savings gained offset the increased costs

With respect to data collection requirements, the relationship between different farm inputs and increases in production underscores the importance of collecting complete data on outputs and inputs.

5.3. Land productivity and farm incomes

Land productivity, as already discussed, is typically measured by physical yields, such as kg per hectare or sacs per acre. Land productivity can also be expressed in monetary units: in this case it represents the gross income or revenue generated by a given unit of land.

Land productivity, or yields, depend, to a large extent, on the quantity and quality of inputs that are devoted to agricultural production: yields are the final outcome of the production process. High yields can reflect efficient farming practices, a highly skilled workforce or the efficient use of machinery and other capital goods. An increase in land productivity or yields is synonymous with higher output per unit of land and, therefore, with higher farm income, that is if everything else is held equal (especially climate conditions).

From a data collection and analytical perspective, properly measuring and understanding the link between land productivity and incomes essentially comes down to the following:

- Adequately measuring land area across its different dimensions: total cultivated area, sown area and harvested area. The lack of proper accounting of the differences between the sown area and the area effectively harvested is one of the main reasons behind poor estimations of yields and, consequently, of outputs and farm incomes.
- Collecting sufficiently detailed and disaggregated data for the major agricultural inputs and production factors.

In addition, as indicated by Kelly et al. (1996), investments in land improvements, such as tree planting, bunds or terracing, can also generate positive effects on cropping yields and, consequently, on incomes. Data series on these types of investments are necessary to properly measure and identify the determinants of yields and incomes. Unfortunately, these data are rarely collected and disseminated, judging by the information available in datasets of international organizations, such as FAO, or in the statistics produced by most national statistical offices.

5.4. Capital productivity and farm incomes

An appropriate combination of capital with other production factors, such as labour and land, can generate higher yields, output and incomes. The impact on farm incomes from an improvement in the returns to capital (revenue per unit of capital used) depends on a series of conditions similar to those that have been already identified for labour.

First, the effect depends on the position of the holding in the marginal revenue curve: considering the case of a holding with very limited amount of capital and/or outdated or obsolete assets, a frequent situation among small farms in developing countries, the benefits of using more and better capital will almost certainly outweigh the costs and result in higher incomes.[18].

Second, the capital purchased and used on the farm has to be adapted to the type of cropping/livestock activity, and to the characteristics of the farm. In particular, the amount invested must be consistent with the capacity of the holding to cover the costs associated with the maintenance of the equipment or infrastructure and, more importantly, with its capacity to honour loan repayments and costs. The higher the amount invested, the higher the annual depreciation costs and the lower the net operating income of the farm (or returns over cash and non-cash costs).

From a data collection perspective, collecting information for a sufficiently wide range of capital assets and their characteristics, such as purchase price, technical parameters, such as horsepower, and expected service life, is needed to properly assess and value the capital stock. Data collection should be customized to the specificities of developing countries and include assets, such as animals used for ploughing and other activities and hand-tractors, which are now rarely found in developed countries.

Furthermore, given the diversity in the inputs and capital assets used by holdings, especially in developing countries, there is need to differentiate data collection and analysis by type of farms, namely the type of production systems. Indeed, the impact of capital use on farm incomes depends on the type

[18] The question of the access to capital, through rental markets or credits, is not addressed here but has been identified as one of the major limitations to mechanization and productivity improvements in the developing world.

of asset: for example, holdings that rely on animal traction may yield higher returns to land and labour than those using mechanical power, as described by Kelly et al. (1996), a finding based on a study conducted in Burkina Faso. As far as capital use and productivity are concerned, stratification by holding size (cultivated area, number of cattle heads), economic size (physical output, gross revenues) and production system (high/low input, for example) may properly segment the sample of holdings according to the quantity and type of capital assets used.

6

United States Department of Agriculture Productivity Measures: a Case Study

6.1. Introduction

The United States Department of Agriculture has a long and rich history of producing agriculture productivity measures. Its agricultural productivity programme, which is considered by many to be the “gold standard” for productivity measures, had been operating since1948.

The reputation of USDA came about as the result of its history of measurement of innovation, a tradition of collaborating with researchers, developing partnerships with academics and sharing expertise internationally.

A no less significant factor is the symbiotic relationship between the analysts and researchers within the Economic Research Service (ERS) and the statisticians and data gathered within the National Agriculture Statistics Service (NASS), both are units of USDA. Having the researchers and the data collectors close and providing continuous feedback only helps to improve the overall statistical programme.

6.2. Productivity measurement

The USDA productivity measures are obtained by using a “growth accounting approach” for measuring productivity. This approach attributes growth in total agricultural output to the different components of production, namely, intermediate inputs, such as fertilizer and pesticides, labour, capital and land. Following economic and index number theory, and under some restrictive assumptions concerning the form of the underlying production function, total factor productivity is defined as the ratio of the quantity of aggregate measures of the outputs relative to the quantity of aggregate measures of the inputs used in the production process. The unexplained growth is said to represent technological growth and, to some extent, measurement error. This approach uses aggregated farm sector production and financial accounting data, such as receipts from the sale of farm products, output prices and expenditures on farm inputs, in an index number procedure to calculate farm output and farm input indices.

In developing the productivity accounts for agriculture, USDA has adopted the gross output model rather than the value-added approach. One of the advantages of this choice is that it explicitly measures the contribution of intermediate inputs, while an inherent disadvantage is that it is not consistent with productivity measures that are based on and consistent with other industries in the national accounting framework. The rationale for adopting the gross output measure is not trivial, as it has been shown that a significant proportion of output growth can be attributed to additional use of improved intermediate inputs for pesticides, fertilizer and herbicides. However, to overcome the issue of intersectors non-comparability inherent in the gross output approach, in the United States statistical system, a separate set of agriculture productivity measures are offered using national accounts for analysts interested in comparing agriculture productivity with productivity in other industries.

Agriculture output

Output is measured as the sum of sales, inventory change and income in kind (home consumption) in value terms and is sourced from USDA farm production and inventory surveys. The valuation of output is from the perspective of the producer and, consequently, subsidies are added and indirect taxes are subtracted. Values are deflated to implicit quantities using producer prices.

It is a commodity-based measure unlike most other business surveys that use the establishment as the unit of observation. USDA-ERS also includes the output of goods and services of certain non-agricultural (or secondary) activities when these activities cannot be distinguished from the primary agricultural activity (Ball et al. 2015)

Inputs include labour, capital (machinery and equipment, buildings, land and inventories) and intermediate inputs, including, among other things, seed, fertilizer, energy pesticides and intermediate livestock inputs, such as feed and veterinary services.

Labour

Labour costs are the sum of wages and benefits paid to hired labour and the imputed wage bill for unpaid family and owner labour. The imputed compensation for unpaid labour is obtained by accessing comparable compensation rates for paid labour with the same demographic characteristics. Adjustments for changes in labour quality are complex and detailed. Matrices of hours worked and compensation per hour have been developed for labourers cross-classified by sex, age, education and employment class (employee, self-employed or unpaid family labour). This is used to develop a quality adjusted labour input.

Capital Inputs

The United States Department of Agriculture uses a capital services model for estimating capital inputs. Because the value of capital used in any one year is difficult to observe, the basic concept of estimating the opportunity cost of the capital service flows used by the sector is applied. The capital service flow for each component of capital input is calculated as the product of the capital stock and its rental price. Implicit rental prices are calculated for each asset type using the expected real rate of return. The real rate of return is calculated as the nominal yield on investment grade corporate bonds, less the rate of asset price inflation (capital gain). The ex-ante rate of inflation is measured using an autoregressive integrated moving average (ARIMA) process.

Intermediate inputs

The USDA survey estimates are used to obtain the value of pesticides, fertilizer, feed, veterinary services, energy and other intermediate inputs.[19]. To take into account the considerable change in the effectiveness of some inputs (pesticides and fertilizer, in particular), ERS has developed quality-adjusted prices for agricultural chemicals and purchased contract services to capture the quality changes embodied in those intermediate inputs. The nominal values of those expenses should be decomposed into constant-quality quantities and constant-quality prices. Failure to do this would understate the "quantity" of the input and overstate the resulting TFP estimate.

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[19] For a complete list, see: www.ers.usda.gov/data-products/agricultural-productivity-in-the-us.aspx.

Deriving productivity measures

Measures of productivity are obtained by dividing a constant dollar series for outputs by a constant dollar series for inputs that are converted into index numbers. Using dollars converted to index numbers permits the aggregation of different outputs and inputs and makes the estimates comparable over time. Because index numbers are used, choosing the form of index number and accounting for quality change for outputs and inputs becomes critical. Considerable academic and empirical research has been undertaken to determine the appropriate index number to use. In line with the recommendations of the American Agriculture Economic Association (AAEA), USDA uses the Tornqvist indices for productivity measurement (Shumway et al. 2015).

Evolution of productivity measurement methods

The USDA approaches to productivity measurement have changed and improved over time. Two independent and comprehensive reviews have been undertaken since 1980 to examine the methods and data sources with the objective to recommend improvements to the existing methodology. The first such review was published in 1980 by the American Agriculture Economics Association review and was led by Bruce Gardner (Gardner et al. 1980).

The principle recommendations from Gardner led to multiple changes in the areas of conceptual and practical productivity measurement. They are as follows:

- Use a Divisia index[20] to aggregate inputs;
- Use direct sampling instead of the "requirements' approach" to construct the labour inputs;
- Adjust the procedures for converting land stock to a service flow;
- Improve statistical data on stocks of machinery and equipment;
- Adopt better procedures to depreciate infrastructures and machinery;

[20] The IMF *Producer Price Index Manual* defines the Divisia approach to index numbers as follows: "A price or quantity index that treats both prices and quantities as continuous functions of time. By differentiation with respect to time, the rate of change in the value of the aggregate in question is partitioned into two components, one of which is the price index and the other the quantity index." www.imf.org/external/np/sta/tegppi/gloss.pdf . In practice, the indices cannot be calculated directly because of data limitations, but they are often approximated through the Tornqvist index.

- Use Bureau of Labour Statistics price indices for machinery to construct farm machinery input indices.

The United States Department of Agriculture has adopted these recommendations[21] and several others. Revisions to concepts, sources and methods have been a continuous process.

The second review, undertaken by Shumway et al. (2015), is currently being considered. The adoption of recommended improvements and continuous collaboration with experts in the field of productivity research has led Shumway (2015) to the following conclusion: "ERS has emerged as an international leader in construction and integration of these accounts in agriculture, and the national (covering all 50 states) and state-level estimates for the 48 contiguous states are widely cited as the basis for both policy and research work."

6.3. Analytical uses

Agricultural productivity measures are deemed important by researchers because as productivity increases in an industry, resources are released and available to be used in other industries. Increased productivity has led to more output and lower real prices for agriculture products that cover the most basic necessities. As a result of the research on productivity, governments can demonstrate the links between better education of the workforce and increased food security and international competitiveness (Fuglie & Heisey 2007). Working with researchers to refine and improve methods is part of the culture of USDA.

Within ERS, there is an international productivity research programme driven by the demand to compare and explain productivity differences among countries. Part of the productivity programme within ERS extends to comparing productivity in the United States with productivity in other countries. This expertise is resident in ERS.

[21]The United States Department of Agriculture uses Tornqvist indices to calculate its agriculture productivity measures.

6.4. Dissemination

The United States Department of Agriculture makes its extensive data available on its website. Researchers can get access to publications, summary findings, datasets and analytical research online. In addition, summary results are made available in an easy to comprehend "Amber Waves" programme that is intended for the non-academic user.

The programme has also added an extensive international dimension to its productivity programme and has taken on the not so trivial task of estimating agriculture productivity for other countries and regions. Expertise is shared with other countries wishing to improve their productivity measurement programme.

6.5. Quality assessments and improvements

The United States Department of Agriculture constantly strives to improve its estimations. The agency has worked with academics and researchers to fine-tune estimation methods. When a revision is made, user notes document the reasons for the change.

6.6. Conclusion

Through its practice of examining current methods with the view to making enhancements and improvements and leading the research and by virtue of a very strong team, the USDA has rightfully earned its reputation for providing the gold standard for agriculture productivity measures.

7
Conclusion

This literature review and gaps analysis has sought to provide operational definitions and measurement methods of agricultural productivity in its different dimensions – partial or multi-input, physical or value-based, farm-level or aggregated. It has also sought to explain how productivity can be decomposed in its main drivers, technical efficiency and technological changes, and how the former can be estimated.

The data required to construct the different productivity indicators have also been identified. In this analysis, the authors have observed that information on output and input prices are needed when aggregating outputs, to determine farm or sector-wide productivity, for example, or inputs, when multi-factor productivity is measured. This requirement is difficult to meet in countries where statistical information is sparse and irregular, which is the case of many developing countries. The need for estimation and imputations of missing data reduces the accuracy of these aggregate-level productivity indicators. Some techniques that are less data demanding but more complex to implement, such as DEA or stochastic frontier analysis, can be used to measure productivity growth and identify the contribution of technical efficiency. These techniques, which have become standard in the academic world, are not often used in national statistical offices.

Accurately measuring productivity requires data on inputs differentiated by type, especially for aggregated indicators. The composition of labour in terms of skills and experience can vary significantly over time and across farms: using similar wages in the index construction procedures would lead to biased estimates of labour productivity. Information on input use and prices by quality classes becomes necessary when price or value-weighted aggregates are computed. Quality-specific data are needed in all cases to understand the extent of the contribution of structural changes (in the composition of labour or in land quality, for example) to productivity growth.

Finally, this study has examined the relationship between productivity and farm incomes. While the link between these two concepts is clearly positive, the extent of the link depends on the boundaries of farm income (in particular, the inclusion of family labour and other farm-produced or owned inputs), the source of productivity and the current situation of the farm in the efficiency curve.

The USDA approach to measure agricultural productivity measurement at the national level, from data collection to productivity indicators and analysis, has been presented in a case study. On many aspects, this programme can be seen as the "gold standard" for productivity measurement that other countries, especially developing countries, can use as a reference. This does not mean that countries should and could adopt this system, given the differences in statistical infrastructures, experiences and policy objectives and priorities. The structure of farming, which in many developing countries is dominated by very small and often subsistence farms, may explain different measurement objectives, such as a focus on such indicators as output quantities per labour unit labour productivity, instead of highly-aggregated value-weighted and data demanding total factor productivity indices.

This work is a prelude to the forthcoming guidelines on agricultural productivity and efficiency measurement. The description of the methods, data and methodological gaps identified here will be expanded in the guidelines, with the objective to propose measurement methods and frameworks that best fit developing countries, in terms of the nature of their agricultural sector, policy objectives and the level of the statistical infrastructure as well as technical and human capacities.

References

Aignier, D., Lovell, K., C.A., & Schmidt, P., 1977 Formulation and Estimation of Stochastic Frontier Production Function Models. *Journal of Econometrics 6* (1): 21-37.

Arnade, C.A. 1994. *Using Data Envelopment Analysis to Measure International Agricultural Productivity*. Tech Bull No. 1831, USDA-ERS, Washington D.C..

Ball, V.E. Bureau, J-C., Nehring, R. & Somwaru, A. 1997. Agricultural Productivity Revisited, *American Journal of Agricultural Economics*, 79 (4): 1045-1063.

Ball, V. E. & Norton G.W. (eds) 2002. *Agricultural Productivity: Measurement and Sources of Growth*, Springer: Berlin.

Ball, V., E., Wang, S., L., Nehring, R., & Mosheim, R.,. 2015. Productivity and Economic Growth in U.S. Agriculture: A New Look. *Applied Economic Perspectives and Policy*, 38(1): 30–49.

Ball, V.E. & Harper, M.J. 1990. Neoclassical Capital Measures Using Vintage Data: An Application to Breeding Livestock, Washington, D.C.: U.S. Bureau of Labor Statistics, Office of Productivity and Technology, unpublished.

Charnes, A., Cooper, W.W. & Rhodes, E., 1978. Measuring the Efficiency of Decision Making Units. *European Journal of Operational Research 2,* 339.

Caves, D., Christensen, L., Diewert, W.E. (1982) *The economic theory of index numbers and the measurement of input, output, and productivity***.** Econometrica Vol 50 N°6.**,** Publication of the Econometric Society.

Cornwall, J. 1987. Total factor productivity, in *The New Palgrave Dictionary of Economics*", 4: 600-662, MacMillan Press, New York.

Crego, A., Larson, D., Butzer, R. & Mundlak, Y. 1998. *A new database on investment and capital for agriculture and manufacturing*. Policy, Research working paper; no. WPS 2013. World Bank: Washington, D.C.

De Avillez, R. 2011. *A detailed analysis of the Productivity Performance of the Canadian primary agriculture sector*, CSLS Research Report 2011-06. Centre for the Study of Living Standards, Ottawa.

Diewert, W.E. 1976. Exact and Superlative Index Numbers. *Journal of Econometrics,* 4 (2):115- 45.

1980. Capital and the Theory of Productivity Measurement, *The American Economic Review,* 70(2): 260-67.

Färe, R., Grosskopf, S., Lovell C.A.K., & Pasurka, C. 1989. *Multilateral* Productivity Comparisons when some Outputs are Undesirable: A Nonparametric Approach, *Review of Economics and Statistics*, 71(1): 90-98.

Fried, H.O., Knox Lovell, C.A. & Schmidt, S. S. 2008. *The Measurement of Productive Efficiency and Productivity Growth*, Oxford University Press: Cambridge, UK.

Fuglie, K.O., Benton, T., Sheng, Y.E., Hardelin, J., Mondelaers, K. & Laborde, D. 2016. G20 MACS White Paper: Metrics of Sustainable Agricultural Productivity.
Available at
http://www.tarim.gov.tr/ABDGM/Belgeler/Uluslararas%C4%B1%20Kurulu%C5%9Flar/G20%20MACS%20White%20Paper%20Ag%20Productivity%20Metrics%204-26-2016_Final.pdf. Accessed on 30 January 2017.

Fuglie K, & Heisey, P.W. 2007. *Economic returns to public agricultural research,* United States Department of Agriculture, Economic Research Service, Economic Brief Number 10. Economic Brief Number 10.

Fuglie, K.O., Wang S., & Ball, E. 2012. *Productivity Growth in Agriculture: An International Perspective.* CAB International: Wallingford, U.K.

Global Strategy to Improve Agricultural and Rural Statistics. 2016. *Handbook on Agricultural Cost of Production Statistics: Guidelines for Data Collection, Compilation and Dissemination*. Rome: FAO.

Gardner, B., Durost, D., Lin, W., Lu, Y-C., Nelson, G., & Whittlesey, N. 1980. *Measurement of U.S. agricultural productivity: a review of current statistics and proposals for change*. Technical Bulletin No. 1614.USDA/ESCS publication, Washington D.C.

Grosskopf, S. 1993. Efficiency and productivity. In Fried, H.O., Lovell, K.C.A., & Schmidt, S.S. (eds). *The Measurement of Productive Efficiency: Techniques and Applications.* Oxford University Press, London.

Grosskopf, S. 2002. Some Remarks on Productivity and its Decomposition. Journal of Productivity Analysis, 20(3): 459-474

Herdt, R.W, & Mandac, A M. 1981. Modern Technology and Economic Efficiency of Philippine Rice Farmers. *Economic Development and Cultural Change*, 29(2).

Jones, L.A. & Durand, D. 1954. Appendix B: some technical terms used in farm income analysis. In *Mortgage Lending Experience in Agriculture,* (pp. 222-226). Princeton University Press/NBER: Princeton, New Jersey, USA.

Jorgenson, D., 1989. *Productivity and Economic Growth*. Ernst R. Berndt and Jack E. Triplett (eds.), Fifty Years of Economic Measurement, University of Chicago Press.

Jorgenson, D. W. & Griliches, Z. 1967. The Explanation of Productivity Change. *Review of Economic Studies,* 34(3), 249-283.

Jorgenson, D.,W., Gollop, F. M., & Fraumeni., B. M. 1987. *Productivity and US. Economic Growth*. Harvard University Press, Cambridge, Mass., USA.

Jorgenson D., Ho, M.S., & Samuels, J.D. 2014. Long-term estimates of U.S. productivity and growth, Paper prepared for presentation at the *Third World KLEMS Conference, Growth and Stagnation in the World Economy*, 19-25 May 2014, Tokyo.

Kelly, V.A., Hopkins, J., Reardon, T., & Crawford, E.W. 1996. *Improving the measurement and analysis of African agricultural productivity promoting complementarities between micro and macro data*. Technical Paper No. 27. Office of Sustainable Development. Bureau for Africa. USAID publication, Washington, D.C.

Le Cotty, T., & Dorin, B. 2012. A Global Foresight on Food Crop Needs for Livestock. *Animal*, (6)9: 1528-1536.

Ludena, C.E. 2010. *Agricultural Productivity Growth, Efficiency Change and Technical Progress in Latin America and the Caribbean*. IDB Working Paper Series 186. Inter-American Development Bank, Washington, D.C.

Lysko, W. 1995. Manufacturing Multifactor Productivity in Three Countries. *Monthly Labor Review*, 118 (7): 39-55.

Mazoyer, M., 2007. La Situation Agricole et Alimentaire Mondiale : Causes, Conséquences, Perspectives. *Recherches Internationals,* 80:47-64.

Mazoyer, M. & Roudart, L. (2006). *A History of World Agriculture. From the Neolithic Age to the Current Crisis*, Earthscan, London.

Meeusen, W., & van den Broeck, J., 1977. Efficiency Estimation from Cobb-Douglas Production Functions with Composed Error. *International Economic Review*, 18 (2): 435-444.

Nishimizu, M. & Page, J. 1982. Total Factor Productivity Growth, Technological Progress and Technical Efficiency Change: Dimensions of Productivity Change in Yugoslavia, 1965-78. *The Economic Journal*, 92(368): 920–936.

Odhiambo, W., Nyangito N.O. & Nzuma, J., 2004. *Sources and determinants of agricultural growth and productivity in Kenya*. KIPPRA Discussion Paper No. 34. Kenya Institute for Public Policy Research and Analysis, Nairobi.

OECD. 2001a. *Measuring Capital: Measurement of, Capital Stocks, Consumption of Fixed Capital, and Capital Services*. OECD, Paris.

OECD. 2001b. *Measuring Productivity – OECD Manual: Measurement of Aggregate and Industry-level Productivity Growth*. OECD, Paris.

Orea, L, 2002. Parametric Decomposition of a Generalized Malmquist Productivity Index. *Journal of Productivity Analysis,* 18 (1): 5-22.

Perdomo, J. & Mendieta, J. (2007), *Factores que afectan la eficiencia técnica y asignativa en el sector cafetero de colombiano: una aplicación con análisis envolvente de datos*, Revista Desarrollo y Sociedad 60.

Sadoulet, E. & de Janvry, A. 1995. *Quantitative Development Policy Analysis*. The Johns Hopkins University Press. Baltimore, Maryland, USA and London.

Schreyer, P., Brandt, N., & Zipperer, V. 2015. *Productivity measurement with natural capital*. OECD Economics Department Working Papers. OECD Publishing, Paris.

Shumway, C.R., Fraumeni, B.M., Fulginiti, L. E., Samuels, J. D. & Stefanou S.E. 2015. *Measurement of U.S. agricultural productivity*: a *2014 review of current statistics and proposals for change*. Working Paper Series WP 2015-12, School of Economic Science, Washington State University, Pullman,Washington, USA.

Solow, R.1957. Technical Change and the Aggregate Production Function. *The Review of Economics and Statistics*, 39(3): 312-329.

Vesterby, M., & Krupa, K.S. 1993. *Effects of Urban Land Conversion on Agriculture.* E. Thunberg and J. Reynolds (eds). SRDC No. 169. Southern Rural Development Center and Farm Foundation, Mississippi State University, Mississippi, USA.

Yotopoulos, P.A., & Lau, L,J. 1973. Test for Relative Economic Efficiency: Some Further Results. *The American Economic Review*, 62(1):214-223.