Chapter 16 *

Productivity Growth and Technology Capital in the Global Agricultural Economy

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16.1 Introduction

The chapters of this volume have presented some of the latest and most comprehensive assessments of productivity growth for agriculture in various countries and regions of the world. As reviewed in the introduction to this volume, the global story is a mixed one. Industrialized countries have generally sustained relatively strong rates of total factor productivity (TFP) over the past several decades, although Australia and South Africa show signs of productivity stagnation. In transition countries there has been a fairly robust productivity recovery after more than a decade of economic reforms that forced a sharp contraction on the agricultural sectors of these countries. But just as the reform process has been uneven across these countries, so has the pace of their agricultural recovery. Among developing countries, several, most notably Brazil and China, have achieved remarkable productivity gains over the past several decades. Others, especially those in sub-Saharan Africa, continue to lag far behind the kind of productivity growth most other countries are achieving.

What does all this add up to? In this closing chapter I have two principal objectives. First, I extend my previous work (Fuglie, 2008, 2010b) on measuring in a consistent and comparably fashion agricultural TFP growth for various countries and regions and for the world as a whole. Second, I re-examine the model in Evenson and Fuglie (2010) on the correlation between national capacities in research and extension with long-run agricultural productivity growth with these updated estimates. I use the national "technology capital" indexes described in Evenson and Fuglie (2010) to test whether developing countries that invested more in technology capital achieved faster growth in agricultural productivity. This work continues a long line of research on the technological determinants of agricultural growth, dating from Hayami and Ruttan (1971, 1985), Evenson and Kislev (1975), Craig, Pardey and Roseboom (1997), Wiebe *et al* (2003) and Avila and Evenson (2010), that seeks to better understand the role of agricultural science and technology in improving food security and economic welfare around the world.

In the next section of this paper I outline a practical, "growth accounting" approach for measuring changes in agricultural TFP across a broad set of countries given limited international data on production outputs, inputs, and their economic values. Considerable attention is given to

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data and measurement issues. Like in my previous work (Fuglie, 2008, 2010b), I adjust agricultural land area for the quality differences among rainfed and irrigated cropland and pastures. Applying the lessons from other chapters in this volume, I use alternative measures (from FAO) for cropland in sub-Saharan Africa (Fuglie and Rada, Chapter 12), agricultural labour in transition countries (Swinnen, van Herck and Liesbet, Chapter 5) and Nigeria (Fuglie and Rada, Chapter 12), and agricultural machinery capital globally (Butzer, Mundlak and Larson, Chapter 15). Although the measure of farm machinery I develop here – which includes a broader set of capital stock than a simple count of tractors in use –is an improvement over previous studies - it still likely falls short of the comprehensive measures described in Butzer, Mundlak and Larson. Getting more complete, global measures of agricultural capital stock is probably the most pressing challenge in improving our ability to decipher the rate and direction of global agricultural productivity growth.

16.2 Methods and Data

16.2.1 Measuring TFP Growth and its Causes

Total Factor Productivity

Here, I sketch out the procedures used to construct internationally comparable measures of agricultural TFP growth relying primarily on FAO data on agricultural inputs and outputs, and supplementary information on production costs from other studies. Zhao, Sheng and Gray (Chapter 4, this volume) presents a thorough discussion of growth accounting methods for assessing changes in agricultural TFP and the reader is referred to this chapter for a more comprehensive conceptual treatment of the subject.

Define total factor productivity (TFP) as the ratio of total output to total inputs in a production process. Let total output be given by Y and total inputs by X. Then TFP is simply:

$$TFP = {}^{Y}\!/_{X}. \qquad (16.1)$$

Changes in TFP over time are found by comparing the rate of change in total output with the rate of change in total input. Expressed as logarithms, changes in equation (16.1) over time can be written as:

$$\frac{d\ln(TFP)}{dt} = \frac{d\ln(Y)}{dt} - \frac{d\ln(X)}{dt} \qquad (16.2)$$

which simply states that the rate of change in TFP is the difference in the rate of change in aggregate output and input.

Agriculture is a multi-output, multi-input production process, so Y and X are vectors. When the underlying technology is represented by a constant-returns-to-scale Cobb-Douglas production function and where (i) producers maximize profits so that the output elasticity with respect to an input equals the cost share of that input and (ii) markets are in long-run competitive equilibrium so that total revenue equal total cost, then equation (16.2) can be written as:

$$\ln\left(\frac{TFP_t}{TFP_{t-1}}\right) = \sum_i R_i \ln\left(\frac{Y_{i,t}}{Y_{i,t-1}}\right) - \sum_j S_j \ln\left(\frac{X_{j,t}}{X_{j,t-1}}\right). \qquad (16.3)$$

where R_i is the revenue share of the ith output and S_j is the cost-share of the jth input. Total output growth is estimated by summing over the growth rates for each commodity weighted by its revenue share. Similarly, total input growth is found by summing the growth rate of each input, weighted by its cost share. TFP growth is just the difference between the growth of total output and total input.

One difference among growth accounting methods is whether the revenue and cost share weights are fixed or vary over time. Paasche and Laspeyres indexes use fixed weights whereas the Tornqvist-Thiel and other chained indexes use variable weights. Allowing the weights to vary reduces potential "index number bias." Index number bias arises when producers substitute among outputs and inputs depending on their relative profitability or cost. In other words, the growth rates in Y_i and X_j are not independent of changes R_i and S_j. For example, if labor wages rise relative to the cost of capital, producers are likely to substitute more capital for labor, thereby reducing the growth rate in labor and increasing it for capital. For agriculture, index number bias in productivity measurement appears to be more likely for inputs than outputs. Cost shares of agricultural capital and material inputs tend to rise in the process of economic development while the cost share of labor tends to fall. Commodity revenue shares, on the other hand, appear to show less change over time.

To reduce potential index number bias in TFP growth estimates, I vary cost shares by decade whenever such information is available. For outputs, however, base year prices (or equivalently, base year revenue shares) are fixed, since these depend on FAO's measure of constant, gross agricultural output (described in more detail below). The base period for output prices is 2004-2006.

A key limitation in using equation (16.3) for measuring agricultural productivity change is a lack of representative cost share data for most countries. Many types of agricultural inputs (such as land and labor) may not be widely traded and heterogeneous in quality, making price or cost determination difficult. Some studies have circumvented this problem by estimating a distance function, such as a Malmquist index, which measures productivity using data on output and input quantities alone (see Nin-Pratt and Yu, Chapter 13 in this volume for a description of this method). But this method is sensitive to the dimensionality problem: results of the model are sensitive to the number of outputs, inputs and countries included in estimation (Lusigi and Thirtle, 1997). Coelli and Rao (2005) have also observed that the input shadow prices derived from the estimation of this model vary widely across countries and over time and in many cases are zero for major inputs like land and labor, which is not plausible. Instead, I compile estimates from previous studies of input cost shares or production elasticities for individual countries or regions and apply these to equation (16.3). For countries for which I lack data on cost shares, I approximate these by applying cost shares from a "like" country. The section below on "input cost shares" provides details on the data sources and assumptions. This is similar to the approach used by Avila and Evenson (2010), who applied agricultural input cost shares from Brazil and

India to other developing countries, except that I use a richer set of information on cost shares and include industrialized and transition countries in the analysis.

The framework outlined above provides a simple means of decomposing the relative contribution of TFP and inputs to the growth in output. Using a dot above a variable to signify its annual rate of growth, the growth in output is simply the growth in TFP plus the growth rates of the inputs times their respective cost shares:

$$Y = TFP + \sum_{j=1}^{J} S_j \dot{X}_j \ . \tag{16.4}$$

I call equation (16.4) an *input cost decomposition* of output growth since each $S_j X_j$ term gives the growth in cost from using more of the jth input to increase output.[1] It is also possible to focus on a particular input, say land (which I will designate as X_1), and decompose growth into the component due to expansion in this resource and the yield of this resource:

$$Y = X_1 + \left(\frac{\dot{Y}}{X_1} \right) \tag{16.5}$$

This decomposition corresponds to what is commonly referred to as *extensification* (land expansion) and *intensification* (land yield growth). We can further decompose yield growth into the share due to TFP and the share due to using other inputs more intensively per unit of land:

$$Y = X_1 + TFP + \sum_{j=2}^{J} S_j \left(\frac{\dot{X}_j}{X_1} \right). \tag{16.6}$$

I call equation (16.6) a *resource decomposition* of growth since it focuses on the quantity change of a physical resource (land) rather than its contribution to changes in cost of production. See Figure 12.3 in Chapter 12 of this volume for a graphical depiction of the growth decomposition described in equation's (16.5) and (16.6).

TFP and Technology Capital

While the growth decomposition described above is useful for illustrating the role of productivity change and resource utilization in expanding output, it does not explain why these trends are

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[1] Strictly speaking, input prices are held constant when estimating total input growth, so any increase in cost comes from using more quantity of the input and not from changes in its price. If input and/or output prices actually change between any two periods over which TFP growth is estimated, this would affect the distribution of the economic gains in TFP but not the measure of TFP growth itself. For example, if output prices fell between the two periods, some of the gains in TFP would be passed on to consumers in the form of lower food prices. If fertilizer prices increased between two periods, some of the gains in TFP would be distributed as higher payments for fertilizers. In competitive equilibrium, any TFP benefits that are retained by the farm sector will be capitalized into the price of sector-specific inputs, namely, land, so as to maintain the zero profit (total cost= total revenue) condition.

occurring. The transition from resource-led to productivity-led growth was a major 20th-Century development in world history (Hayami and Ruttan, 1971, 1985). But the speed at which various countries have made this transition has varied widely, and for some countries hardly at all. Hayami and Ruttan (and others since them) attributed the different rates of productivity growth to differences in their accumulation of human capital, which they took especially to mean formal institutions conducting agricultural research and development (R&D). Hayami and Ruttan lacked sufficient data to characterize R&D investments, however, and proxied for this using labor force education. Since their work a great deal of data has been accumulated on national capacities in R&D as well as agricultural extension and general education, which Robert Evenson developed into indexes of "technology capital" (Evenson and Fuglie, 2010; Avila and Evenson, 2010). I use these indexes of national technology capital to explore whether they can explain differences in agricultural productivity performance among countries. My approach is similar to that used in Evenson and Fuglie (2010) and Avila and Evenson (2010), in which estimates of long-run average TFP growth are regressed against indexes of national technology capacities. These technology capital indexes, one measuring a nation's ability to invent and innovate new agricultural technology and a second a nation's ability to extend new technologies to farmers, are briefly presented here and described in more detail in the two references above.

To represent the capacity to develop or adapt new agricultural technology, an "Invention-Innovation" (**II**) index is constructed from two indicators, the number of public-sector agricultural scientists per thousand hectares of arable land (Pardey, Roseboom and Anderson, 1991, and updated from Agricultural Science and Technology Indicators). and industry research and development as a percentage of GDP (UNESCO). Agricultural scientists per crop area represent capacity to breed and adapt appropriate varieties and agronomic practices for the crops and environments in a country. The UNESCO indicator captures a country's capacity to adapt and manufacture appropriate industrial inputs for agriculture. Similarly, the capacity to extend and adopt agricultural technology is represented by an index of "Technology Mastery" (**TM**). The **TM** index is also a composite of two indicators, the number of extension workers per thousand hectares of arable land and the average years of schooling of males over 25.[2] Values for the **II** and **TM** indexes are constructed for a set of 87 developing countries for two points in time: the average capacity scores over 1970-75 and 1990-95. Each index ranges in value from 2 through 6, with 2 representing countries with minimal or no capacity (i.e., no formal research; no extension service and a largely illiterate population) and 6 countries that have acquired capacities comparably to that of developed countries (Evenson and Fuglie, 2010).

To examine the relationship between technology capital and productivity growth, technology capital in period t is hypothesized to influence long-run average TFP growth over subsequent years. Since the technology capital indexes have been constructed for two periods, we effectively have a two-period panel dataset. We let the **II** and **TM** levels in 1970-75 explain average annual TFP growth during 1971-1990 and **II** and **TM** levels in 1990-95 explain TFP growth during 1991-2009. Causality between technology capital and productivity growth in established through

[2] Comprehensive statistics on national agricultural extension services are lacking, but I have compiled what information is available from Judd, Boyce and Evenson (1991) with updates from Swanson *et al* (1990). The average years of schooling for adult males in the labor force are from Barro and Lee (2001). These are for the labor force as a whole and may overstate average schooling levels of agricultural labor.

the lag structure of the model (i.e., present technology capital affects future growth performance) and the panel structure of the data (through a difference-in-difference model, described in equation (16.8) below).

The first estimating equation examines the interaction between research and extension. It is often contended that a lot of technology, often imported, is "on the shelf" but has not diffused because of poor extension services or low farmer schooling. Others maintain that agricultural technology requires innovation and adaptation to local conditions before it can be successfully adopted, and therefore local research capacity is the limiting factor. We examine this question by comparing the productivity performance between countries that have given relatively more or less emphasis to research versus extension and education. These factors enter the equation as a series of indicator variables describing different combinations of II and TM capacities. This estimating equation is given by

$$\overline{TFP}_p \equiv \frac{\sum_{k=0}^{19} \left(\dot{TFP}_{c,p+k} \right)}{20} = \sum_{i=2}^{6} \sum_{j=2}^{6} \delta_{i,j} Dij_{c,p}. \qquad (16.7)$$

where $\dot{TFP}_{c,t} = \ln \left(TFP_{c,t} / TFP_{c,t-1} \right)$ is the growth rate in country c's agricultural TFP in year t and $\mathbf{Dij_{c,p}}$ is an indicator variable for the country's II and TM capacities in the base period p (p = 1970 and 1990).[3] $\mathbf{Dij_{c,p}}$ takes on a value of 1 if both $II_{c,t}$ = i and $TM_{c,t}$ = j, and 0 otherwise. The dependent variable $\overline{TFP}_p$ is the average annual TFP growth rate over the 20-year period subsequent to when technology capacities (the **Dij** indicator variables) are observed. Since $II_{c,t}$ and $TM_{c,t}$ each have 5 levels (i.e., they take on values from 2 to 6), there are potentially 25 different combinations of **II** and **TM** capitals. Thus equation (16.7) could have as many as 25 **Dij** indicator variables, although only 19 such combinations are present in the data. The indicator variable coefficients $\delta_{II,TM}$ measure the average long-run TFP growth rate for all the countries with this II and TM combination. Looking at productivity growth in the years after II and TM are measured accounts for the lag between when research is done and when it new technology resulting from that research is likely to be adopted by farmers.

Note that the model structure in equation (16.7) is a very flexible form – productivity growth for any II and TM combination is independent of productivity growth of any other combination. Another advantage of the model is that it allows us to examine the marginal effects of changes in the one type of technology capital given some level of the other. Holding II (research capacity) at some level J and then examining how the coefficients $\delta_{J,2}...\delta_{J,6}$ vary allows us to examine how marginal increases in TM (agricultural extension and schooling) affect TFP growth. Similarly,

[3] Actually, II and TM capacities are measured as an average of observed data from the 1970-75 and 1990-95 periods. Due to the spotty nature of the data, it is only possible to derive consistent measures of these indicators for a large number of countries by taking observations over a period of nearby years. For convenience, I refer to these measures as "1970" and "1990" capacities.

examining the values of coefficients $\delta_{2,K}...\delta_{6,K}$ allow us to say something about the marginal effect of research capacity holding TM fixed at some level K.

One limitation of the model in equation (16.7) is that it does not control for other factors that may be correlated with both TFP growth and technology capital. The panel structure of the data allows for a more rigorous test of the relationship between technology capital and TFP growth by estimating a "difference in difference" model. By taking first differences of the variables, we can assess whether countries that *increased* their technology capital between 1970 and 1990 were able to *accelerate* productivity growth in agriculture compared with countries that did not. The estimating equation for this version of the model is given by:

$$\left(\overline{TFP}_{p+1} - \overline{TFP}_{p}\right) = \delta_{II}\left(II_{c,p+1} - II_{c,p}\right) + \delta_{TM}\left(TM_{c,p+1} - TM_{c,p}\right) \qquad (16.8)$$

In equation (16.8), the dependent variable is the change in the average TFP growth rate between the two periods (1971-1990 and 1991-2009). The explanatory variables are the changes in II and TM capitals between 1970 and 1990. The coefficients δ_{II} and δ_{TM} indicate the average rate by which TFP growth changed as countries increased (or decreased) their II ant TM capacities by one unit between the two periods. Equation (16.8) is estimated using data for all the developing countries in the sample as well as separately for three regional groups of countries (Latin American, sub-Saharan African and Asia) to see whether there may be systematic differences across regions.

It is important to consider whether the estimates of equation's (16.7) and (16.8) may suffer from omitted variable bias. In addition to technology and human capital, TFP growth may be affected by errors in measurement, "left-out" factors of production, infrastructure, weather fluctuations, civil disturbances, economies of scale, gains in allocative efficiency from market liberalization and other variables. Although the "difference in difference" model removes some country-specific factors that may influence TFP growth, it does not control for changing circumstances within countries. However, several of these omitted variables are probably not relevant to our model because of the long period over which we measure TFP growth (i.e. we take average TFP growth over 20 years). Thus, short-run fluctuations to output or TFP due to natural or civil disturbances will tend to be averaged out. Regarding scale economies, Hayami and Ruttan (1985) and Binswanger, Deininger and Feder (1995) find little evidence that farm size explains productivity differences among developing countries. For infrastructure, Evenson and Fuglie (2010) included a road density variable in their model, but this was not significant in explaining TFP growth across countries so is excluded here. Market liberalization and institutional reforms that improve allocative efficiency will also cause TFP to grow, although the effect may only be temporary since once resources have been reallocated to realize the efficiencies, growth will again stagnate unless improved technology is forthcoming. For productivity growth to be sustained over the long run, it is difficult to conceive of factors other than science and technology that could explain major differences across countries.

16.2.2 Data

FAO's 1961-2009 annual time series of crop and livestock commodity production and land, labor, livestock capital, fertilizer and machinery resources are the primary source for agricultural outputs and inputs used to construct the national and global productivity measures. In some cases these are modified or supplemented with data from other sources (national statistical agencies, mostly) where alternative data are considered to be more accurate or up-to-date, as described below.

Output

For agricultural output, FAO publishes data on annual production of 198 crop and livestock commodities by country since 1961, aggregates this into a measure of the gross production value using a common set of commodity prices from 2004-2006 and expresses this in constant 2005 international dollars. FAO excludes production of animal forages but includes crop production that is used for animal feed and seed in estimating gross production value. The FAO also provides a measure of output net of domestic production used for feed and seed. However, the net production measure does not exclude imported grain that may be used as feed or seed, or grain that is exported and used in another country for these purposes.

Because current (or near current) prices are fixed to aggregate quantities and measure changes in real output over time, the FAO gross production value is equivalent to a Paasche quantity index. The set of common commodity prices is derived using the Geary-Khamis method. This method determines an international price p_i for each commodity which is defined as an international weighted average of prices of the i-th commodity in different countries, after national prices have been converted into a common currency using a purchasing power parity (PPP_j) conversion rate for each j-th country. The weights are the quantities produced by the country. The computational scheme involves solving a system of simultaneous linear equations that derives both the p_i prices and PPP_j conversion factors for each commodity and country. The FAO updates these prices every five years and recalculates its index of gross production value back to 1961 using its most recent set of international prices. See Rao (1993) for a thorough description and assessment of these procedures.

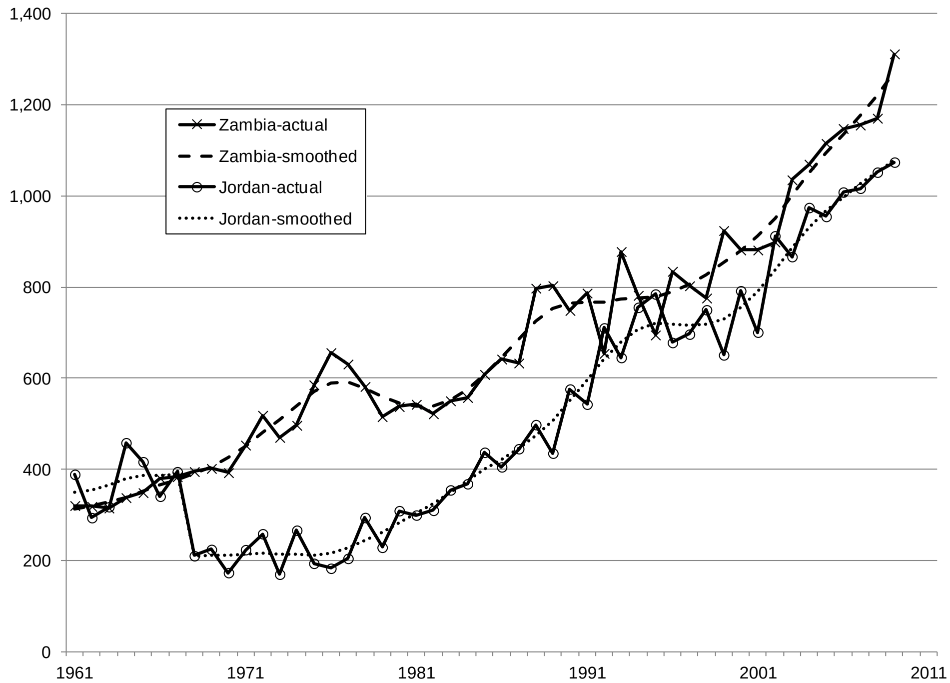
I use the FAO value of gross agricultural output in constant 2005 international dollars as the basis for a consistent measure of output for each country and the world. However, due to the influence of weather and other factors, agricultural production is exceptionally volatile from year to year, and it can be difficult to disentangle short-run fluctuations from long-term trends. To relieve the data of some of these fluctuations, I smooth the output series for each country using the Hodrick-Prescott filter (setting λ=6.25 as recommended for annual data by Ravn and Uhlig, 2002). Figure 16.1 illustrates the effect of this smoothing technique on gross agricultural output for Zambia and Jordan.[4] It is evident that even with smoothing there is still considerable curvature in the output series, although much of the year-to-year fluctuation in output has been removed from the data. I assume that the smoothed series provides a better indicator of

[4] Note that the series for Jordan includes a break in the smoothed series between 1967 and 1968. Prior to 1968 FAO's agricultural data for Jordan includes production from the West Bank. But following the Six Day War when the West Bank came under Israeli control, agricultural production from the West Bank is excluded from Jordan's output. Jordan appears to be an exception in the FAO data in that it does not represent a continuous geographic area for the years in which it is included.

productivity trends and that annual variation around this trend is primarily due to short-term disturbances like weather.

Figure 16.1 - The Effects of Smoothing on Gross Agricultural Output Measures

Agricultural Output
Millions constant 2005 international dollars



The dashed curves are output series that have been smoothed using the Hodrick-Prescott filter. This is meant to remove some of the annual fluctuations in output due to weather and other short-run disturbances but preserve sufficient curvature to capture productivity trends.

Inputs

For agricultural inputs, FAO publishes data on cropland (total and irrigated), permanent pasture, labor employed in agriculture, animal stocks, the number of tractors in use, and inorganic fertilizer consumption. I supplement these data with better or more up-to-date data from national or industry sources when available. For fertilizer consumption, the International Fertilizer Association has more up-to-date and accurate statistics than FAO on fertilizer consumption by country, except for small countries. For agricultural statistics on China, a relatively comprehensive dataset is available from the Economic Research Service (b) with original data from the National Bureau of Statistics of China. For Brazil, I use results of the recently published 2006 Brazilian agricultural census (IBGE) and for Indonesia, I compiled improved data on agricultural land and machinery use (Fuglie, 2010a). For Taiwan, I use statistics from the Council of Agriculture. For the countries of the former Soviet Union, FAO reports data only from 1991 and onward. I extend the time series for each of the former Soviet Socialist Republics (SSRs) back to 1965 from Shend (1993). Also, since FAO labor force estimates for former SSRs and Eastern Europe are not reliable for the post 1990 years (Lerman *et al*, 2003; Swinnen, Dries, and Macours, 2005), sources I use for agricultural labor data are EUROSTAT for the Baltic states and Eastern Europe, CISSTAT for Russia, Belorussia and Moldova, the International

Labor Organization's LABORSTA for Ukraine, and national data reported by the Asian Development Bank for Asiatic former Soviet republics.

Inputs are divided into five categories. *Farm labor* is the total economically active adult population (males and females) in agriculture. *Agricultural land* is the area in permanent crops (perennials), annual crops, and permanent pasture. Cropland (permanent and annual crops) is further divided into rainfed cropland and cropland equipped for irrigation. However, for agricultural cropland in Sub-Saharan Africa I use total area harvested for all crops rather than the FAO series on arable land (see Fuglie and Rada in Chapter 12 of this volume for a discussion of why this series appears to be a better measure of agricultural land in this region). For China I use sown crop area for cropland in that country, given unreasonably discontinuities in both the FAO and Economic Research Service's arable land series for China.[5] I then aggregate rainfed cropland, irrigated area and permanent pasture into a quality-adjusted measure that gives greater weight to irrigated cropland and less weight to permanent pasture in assessing agricultural land changes over time (see the next section on "land quality"). *Livestock* is the aggregate number of animals in "cattle equivalents" held in farm inventories and includes cattle, camels, water buffalos, horses and other equine species (asses, mules, and hinnies), small ruminants (sheep and goats), pigs, and poultry species (chickens, ducks, and turkeys), with each species weighted by its relative size. The weights for aggregation are based on Hayami and Ruttan (1985, p. 450): 1.38 for camels, 1.25 for water buffalo and horses, 1.00 for cattle and other equine species, 0.25 for pigs, 0.13 for small ruminants, and 12.50 per 1,000 head of poultry. *Fertilizer* is the amount of major inorganic nutrients applied to agricultural land annually, measured as metric tons of N, P_2O_5, and K_2O nutrients. *Farm machinery* is an aggregation of 4-wheel riding tractors, 2-wheel pedestrian tractors, and power harvester-threshers in use, adjusted by the average metric horsepower for each kind of machine. The FAO reports time series data for only 4-wheel tractors and harvest-threshers; it recorded information 2-wheel tractors in the 1970s then discontinued this series until recommencing it again in 2002. For interim years I collected national farm machinery statistics on 2-wheel tractors for the following Asian countries: China, Japan, South Korea, Taiwan, Thailand, Philippines, Indonesia, Indian, Bangladesh, Pakistan and Sri Lanka. These are the main countries where pedestrian tractors are widely employed. For aggregation purposes, I assume the following average metric horsepower (CV) per machine: 40 cv for 4-wheel tractors, 12 cv for 2-wheel tractors, and 25 cv for power combines.[6]

While these inputs account for the major part of total agricultural input usage, there are a few types of inputs for which complete country-level data are lacking, namely, use of chemical pesticides, seed, prepared animal feed, veterinary pharmaceuticals, energy, and farm structures. However, more detailed input data are available for several of the countries from which I have

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[5] Fan and Zhang (1997) also used sown area in their study of agricultural productivity in China. Both the FAO and ERS series on arable land in China show huge discontinuities in the 1970s or 1980s due to statistical changes to reporting methods. Nonetheless, the sown area series likely overstates growth in cropland somewhat since it includes increases in cropping intensity due to expansion of irrigation and other factors.

[6] Some adjustments to these data should be noted. The FAO figure for the number of power thresher-harvesters in use in Indonesia actually includes both pedal and power threshing machines. I include only power thresher-harvesters from Indonesian national data. China reports total "power" employed in agriculture in terms of kilowatts, but this likely includes some post-harvest processing machinery like grain mills and oilseed crushers in addition to on-farm machinery. I only include tractors (4-wheel and 2-wheel) and power thresher-harvesters in estimating total farm machinery horse power for China.

data on input cost shares. To account for these inputs, I assume that their growth rate is correlated with one of the five input variables just described and include their cost with the related input. For example, services from capital in farm structures as well as irrigation fees are included with the agricultural land cost share; the cost of chemical pesticide and seed is included with the fertilizer cost share; costs of animal feed and veterinary medicines are included in the livestock cost share, and other farm machinery and energy costs are included in the tractor cost share. So long as the growth rates for the observed inputs and their unobserved counterparts are similar, then the model captures the growth of these inputs in the aggregate input index.

Land Quality

The FAO agricultural database provides time-series estimates of agricultural land by country and categorizes this as either cropland (arable and permanent crops) or permanent pasture. It also provides an estimate of area equipped for irrigation. The productive capacity of land among these categories and across countries can be very different, however. For example, some countries count vast expanses of semi-arid lands as permanent pastures even though these areas produce very limited agricultural output. Using such data for international comparisons of agricultural productivity can lead to serious distortions, such as significantly biasing downward the econometric estimates of the production elasticity of agricultural land (Peterson, 1987; Craig, Pardey, and Roseboom, 1997).

In this study, because I estimate only productivity growth rather than productivity levels, differences in land quality across countries is less of a problem. The estimates depend only on changes in agricultural land and other inputs over time. However, a bias might arise if changes occur unevenly among land classes. For example, adding an acre of irrigated land would likely make a considerably larger contribution to output growth than adding an acre of rain-fed cropland or pasture. To account for the contributions to growth from different land types, I derive weights for irrigated cropland, rain-fed cropland, and permanent pastures based on their relative productivity and allow these weights to vary regionally. In order not to confound the land quality weights with productivity change itself, the weights are estimated using country-level data from the beginning of the period of study (i.e., using average annual data from 1961-1965). I first construct regional indicator variables ($REGION_i$, i=1,2,…5, representing developed and former Soviet countries, Asia-Pacific, Latin America and the Caribbean, West Asia and North Africa, and Sub-Saharan Africa), and then regress the log of agricultural land yield against the proportions of agricultural land in rain-fed cropland (*RAINFED*), permanent pasture (*PASTURE*), and irrigated cropland (*IRRIG*). Including slope indicator variables allows the coefficients to vary among regions:

$$\ln\left(\frac{Ag\ output}{Cropland\ +Pasture}\right) = \sum_i \alpha_i \left(RAINFED * REGION_i\right) + \sum_i \beta_i \left(PASTURE * REGION_i\right) + \sum_i \gamma_i \left(IRRIG * REGION_i\right). \tag{16.9}$$

The coefficient vectors **α**, **β** and **γ** provide the quality weights for aggregating the three land types into an aggregate land input index. Countries with a higher proportion of irrigated land are likely to have higher average land productivity, as will countries with more cropland relative to pasture. The estimates of the parameters in equation (16.9) reflect these differences and provide a ready means of weighting the relative qualities of these land classes. Because of the limited amount of irrigated cropland in some regions, the coefficient on *IRRIG* was held constant across all developing country regions.

Coefficient estimates for each region were divided by α_i. Thus, the normalized β and γ coefficients indicate the productivity of pasture and irrigated land relative to rainfed cropland (the normalized α coefficients equal 1). The regression estimates show that, on average, one hectare of irrigated land was between two and three times as productive as rainfed cropland, which in turn was 10-20 times as productive as permanent pasture, with some variation across regions (see lower part of Table 16.1 for the normalized land quality coefficients for each region). The results give plausible weights for aggregating agricultural land across broad quality classes. In fact, this approach to account for land quality differences among countries is similar to one developed by Peterson (1987), who derived land quality weights by regressing average cropland values in U.S. states against the share of irrigated and unirrigated cropland and long-run average rainfall. He then applied these regression coefficients to data from other countries to derive an international land quality index. The advantage of my model is that it is based on international rather than U.S. land yield data and provides results for a larger set of countries.

The effects of this land quality adjustment on global land use change are shown in Table 16.1. When summed up using unadjusted data, between 1961 and 2009 total global agricultural land expanded from 4,437 million ha to 4,880 million ha, or by about 10%. When adjusted for quality, "effective" agricultural land expanded by 31%, or three times the rate of growth in raw area. The reason is that irrigated area expanded much faster than other types of land and when weighted for its greater productivity, it implies a much greater expansion in "effective" agricultural land. For the purpose of TFP calculation, accounting for the changes in the quality of agricultural land over time increases the growth rate in total agricultural inputs and commensurately reduces the estimated growth in TFP.

This adjustment for changes in different classes of land allows us to further refine the resource decomposition of output growth in equation (16.6) to isolate the contribution of irrigation apart from expansion in cropland area to output growth. Letting X_1 be the quality adjusted quantity of (rainfed cropland equivalent) land, a change in X_1 is given by

$$\Delta X_1 = \Delta\ Cropland\ +\ \beta\Delta\ Pasture\ +\ \gamma - 1\ \Delta\ Irrigated\ area\ . \qquad (16.10)$$

The first two terms indicate the expansion in land area (with growth in pasture area adjusted for quality to put in on comparable terms with cropland expansion). The third term isolated the contribution to growth from irrigation expansion: $\gamma - 1\ * 100\%$ gives the percent augmentation to yield by equipping an acre of cropland with supplemental irrigation. Dividing equation (16.7) by X_1 converts the expression into percentage changes so that it shows the respective contributions of changes in rainfed cropland, pasture area and irrigation to output growth. Combined with equation (16.6), the resource decomposition expression shows the contributions to agricultural growth from changes in agricultural land, water resource use, other inputs per hectare of land, and TFP.

Input Cost Shares

The FAO (and supplementary) quantity data allow us to calculate the growth rates for five categories of production inputs (land, labor, machinery capital, livestock capital, and material inputs represented by fertilizer), but to combine these into an aggregate input measure requires information on their cost shares or production elasticities. For this I draw upon other productivity studies that have compiled relatively complete measurements for selected countries and then assign these as “representative” input cost shares for different regions of the world. Table A16.2 in the appendix shows the input cost shares or production elasticities compiled from fourteen studies (eight from developed countries, six from developing countries and two from transition countries or regions) and the regions to which these were applied for the purpose of input aggregation. For instance, the cost shares for Brazil were applied to South America, West Asia, and North Africa, the cost shares for India were applied to other countries in South Asia and the cost shares for Indonesia were applied to developing countries in Southeast Asia and Oceania. These assignments were based on judgments about the resemblance among the agricultural sectors of these countries. Countries assigned to the cost shares from Brazil tended to be middle-income countries having relatively large livestock sectors, for example.

While the assignment of cost shares to countries lacking input cost data is unfortunate, an argument in favor is that there is a significant degree of congruence among the cost shares reported for the country studies shown in Table A16.2. For the developing-country cases (India, Indonesia, China, Brazil, Mexico, and Sub-Saharan Africa), the cost shares indicate that traditionally farm-supplied inputs (land, labor, and livestock capital) dominate the agricultural production process. These three input classes accounted for between 60% and 98% of total resources in production, while inputs supplied by industry (machinery, or fixed capital, and purchased materials such as fertilizers), accounted for a far smaller share of resources. The cost share of inputs supplied by industry rises with the income of a country, and accounts for a third or more of total costs in the more highly industrialized countries. The use of modern inputs in transition countries, on the other hand, fell sharply after reforms were initiated in the early 1990s, and this is reflected in the cost shares for these countries.

Table 16.1 - Global Agricultural Land Use Changes Between 1961 and 2009

Total Agricultural Land (millions of hectares)

	Rainfed Cropland			Irrigated Cropland			Permanent Pasture			Total Agricultural Land		
Region	1961	2009	% change	1961	2009	% change	1961	2009	% change	1961	2009	% change
Developed Countries	391	371	-5	28	47	66	886	767	-13	1,277	1,139	-11
Transition countries	283	246	-13	11	25	123	358	378	6	641	624	-3
Developing countries	666	938	41	100	233	132	1,853	2,180	18	2,519	3,117	24
World	1,340	1,555	16	140	305	118	3,097	3,325	7	4,437	4,880	10

Total Agricultural Land in Quality-Adjusted Units (millions of hectares of "rainfed cropland equivalents")

	Rainfed Cropland			Irrigated Cropland			Permanent Pasture			Total Agricultural Land		
Region	1961	2009	% change	1961	2009	% change	1961	2009	% change	1961	2009	% change
Developed Countries	391	371	-5	61	101	66	84	72	-13	535	544	2
Transition countries	283	246	-13	28	61	123	10	11	6	320	318	-1
Developing countries	666	938	41	215	501	132	175	205	18	1,056	1,644	56
World	1,340	1,555	16	304	662	118	268	289	8	1,912	2,506	31

Land Quality Adjustment Factors

	World	DC	LDC	SSA	LAC	WANA	Asia LDC
Rainfed cropland	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Irrigated cropland	2.13	2.15	2.50	1.74	1.01	1.45	2.99
Permanent pasture	0.03	0.09	0.03	0.02	0.03	0.02	0.06

DC = developed and transition countries; LDC = less developed countries. SSA=sub-Saharan Africa; LAC=Latin America & Caribbean; WANA=West Asia and North Africa.

Source: Agricultural land area from FAO, with adjustments made for Indonesia and China. Cropland includes FAO's measure of arable land and land under permanent crops except for sub-Saharan Africa, where cropland equals total area harvested. Cropland for China is total sown area. Land quality adjustments reflect the average productivity of different land types relative to rainfed cropland and are derived from regressions (see text).

Country and Regional Productivity

The methodology and data described above allow me to calculate agricultural TFP indexes for nearly every country of the world on an annual basis since 1961. However, some countries have dissolved or are too small to have complete data. For the purpose of estimating long-run productivity trends, I aggregate some national data to create consistent political units over time. For example, data from the nations that formerly constituted Yugoslavia are aggregated to make comparisons with productivity before Yugoslavia's dissolution; data were aggregated similarly for Czechoslovakia, Ethiopia and the former Soviet Union (I also construct TFP series for individual SSR's beginning in 1965). Because some small island nations have incomplete or zero values for some agricultural data, I constructed three composite "countries" by aggregating available data for island states in the Lesser Antilles, Micronesia, and Polynesia. The countries included in the analysis account for more than 99.7% of FAO's global gross agricultural output. The only areas not included in the analysis that have significant agricultural production are the West Bank and Gaza.

In addition to individual countries, I aggregate the data and construct TFP indexes at the regional level. Input and output quantity aggregation is straight forward since they are all measured in the same units (although not adjusted for quality differences in the inputs). To obtain cost shares at the regional level, I take the weighted averages of the cost shares for the countries composing that region. The weights are the country's share of total costs (or revenue) within the region. In this way, I obtain TFP indexes for "North America," "Transition countries of the former Soviet bloc," "the Sahel," etc. Table 16.2 provides a complete list of countries included in the analysis and their regional groupings.

Table 16.2 - Countries and Regional Groupings Included in the Productivity Analysis

Sub-Saharan Africa (SSA)						
Central	**Eastern**	**Horn**	**Sahel**	**Southern**	**Western**	**Nigeria**
Cameroon	Burundi	Djibouti	Burk. Faso	Angola	Benin	
CAR	Kenya	Ethiopia[b]	C. Verde	Botswana	Côte d'Ivoire	
Congo	Rwanda	Somalia	Chad	Comoros	Ghana	
Congo, DR	Seychelles	Sudan	Gambia	Lesotho	Guinea	
Eq. Guinea	Tanzania		Mali	Madagascar	G. Bissau	
Gabon	Uganda		Mauritania	Malawi	Liberia	
Sao Tome & Principe			Niger	Mauritius	Sierra Leone	
			Senegal	Mozambique	Togo	
				Namibia		
				Réunion		
				Swaziland		
				Zambia		
				Zimbabwe		
Latin America & Caribbean (LAC)					**N. America**	**Africa, Developed**
Northeast	**Andes**	**S. Cone**	**C. America**	**Caribbean**		
Brazil	Bolivia	Argentina	Belize	Bahamas	Canada	South Africa
Fr. Guiana	Colombia	Chile	Costa Rica	Cuba	USA	
Guyana	Ecuador	Paraguay	El Salvador	Dom. Rep.		
Suriname	Peru	Uruguay	Guatemala	Haiti		
	Venezuela		Honduras	Jamaica		
			Mexico	Les. Antilles [a]		
			Nicaragua	Puerto Rico		
			Panama	Trin. & Tob.		
Asia				**Former Soviet Union**		
Developed	**NE Asia, LDC**	**SE Asia**	**South Asia**	**Baltic**	**E. Europe**	**CAC**
Japan	China	Brunei	Afghanistan	Estonia	Belarus	Armenia
Korea, Rep.	Korea, DPR	Cambodia	Bhutan	Latvia	Kazakhstan	Azerbaijan
Taiwan	Mongolia	Indonesia	Nepal	Lithuania	Moldova	Georgia
Singapore		Laos	Sri Lanka		Russia	Kyrgyzstan
		Malaysia	Bangladesh		Ukraine	Tajikistan
		Myanmar	India			Turkmenistan
		Philippines	Pakistan			Uzbekistan
		Thailand				
		Viet Nam				
Europe			**West Asia & North Africa**		**Oceania**	
Northwest	**Southern**	**Transition**	**West Asia**	**North Africa**	**Developed**	**Developing**
Austria	Cyprus	Albania	Bahrain	Algeria	Australia	Fiji
Belgium-Lux.	Greece	Bulgaria	Iran	Egypt	N. Zealand	Micronesia [a]
Denmark	Italy	Czechoslovakia[b]	Iraq	Libya		N. Caledonia
Finland	Malta	Hungary	Israel	Morocco		PNG
France	Portugal	Poland	Jordan	Tunisia		Polynesia [a]
Germany	Spain	Romania	Kuwait			Solomon Is.
Iceland		Yugoslavia[b]	Lebanon			Vanuatu
Ireland			Oman			
Netherlands			Qatar			
Norway			S. Arabia			
Sweden			Syria			
Switzerland			Turkey			
UK			UAR			
			Yemen			

[a] Composite countries composed of several small island nations. LDC = developing countries. CAC = C. Asia & Caucasia.
[b] Statistics from the successor states of Ethiopia (Ethiopia and Eritrea), Czechoslovakia (Czech and Slovak Republics), and Yugoslavia (Slovenia, Croatia, Bosnia, Macedonia, Serbia and Montenegro) were merged to form continuous time series from 1961 to 2009.

16.3 Results

16.3.1 Growth Rates for Agricultural Total Factor Productivity

Before discussing country and regional estimates of agricultural TFP growth, Table 16.3 provides productivity measures for the global agricultural economy as a whole. The figures show average annual growth rates by decade since 1961. Output growth has remained remarkably consistent over time, 2.7%/year in the 1960s and between 2.1% to 2.5%/year every decade since then. The source of output growth, however, shifted from being primarily input-driven to productivity-driven. Annual growth in total inputs fell from 2.5% in the 1960s to 0.7% in the 2000s (it was even lower in the 1990s but this was affected by a sharp contraction in the agricultural sector of the former Soviet bloc countries). Annual TFP growth, meanwhile, rose from 0.2% in the 1960s to about 1.7% since 1990.

Labour productivity growth has tended to lag growth in land productivity (since the number of workers in agriculture has been expanding faster than agricultural land area), but labor productivity growth accelerated after the 1980s and was growing at about 2.3% during 2001-2009.

Growth in agricultural output per total agricultural land area (total yield) has mimicked the trends in output growth, remaining fairly steady around an average of 2.1%/year over the past 50 years. The growth rate in cereal yield, however, showed signs of slowing after 1990. Global cereal yield was increasing by about 2.5%/year in the 1970s and 1980s but by only 1.3%/year during 1991-2009. However, the decline in cereal yield growth does not appear to be representative of agriculture as whole. It has been offset by productivity improvements elsewhere - rising yield growth in other commodities and greater intensification of land use - to keep total output per hectare of agricultural land rising at historical rates. Note that growth in global agricultural TFP is generally lower than growth in both land productivity and labor productivity. This reflects an intensification of capital improvements and material inputs in agriculture, which raise land and labor productivity but are removed from growth in TFP.

The decomposition of global output growth into contributions from inputs and TFP is depicted in Figure 16.2. Panel A shows the contributions of various inputs to growth according to their share of total costs (see equation 16.4), and the residual (output growth above total input growth) which we define as TFP. The height of each column gives the average annual rate of growth output over the period. The first column shows the average over the entire 1961-2009 period and the following columns show growth by decade. Over this 48-year period, total inputs grew at about 60% as fast as gross agricultural output, implying that improvement in TFP accounted for about 40% of output growth. However, TFP's contribution to output growth grew over time, and by the most recent decade (2001-2009), TFP accounted for 74% of the growth in global agricultural production.

Figure 16.2a shows the changing composition of input growth over time. Growth in material inputs, especially fertilizers, was a leading source of agricultural growth in the 1960s and 1970s, when green revolution cereal crop varieties became widely available in developing countries. Fertilizer use also expanded considerably in the Soviet Union during these decades, where they were heavily subsidized. The exceptionally low rate of input growth in global agriculture during the 1990s was due primarily to the rapid withdrawal of resources from agriculture in the countries of the former Soviet bloc. By the early 2000s agricultural resources in this region had stabilized and there was a recovery in the rate of global input growth compared with the 1990s. Growth in agricultural labor tends to follow population growth rates in low income countries but turns negative through structural transformation when countries become richer (see Binswanger-Mkhize and d'Souza, Chapter 9 of this volume). By the most recent decade (2001-2009), the global agricultural labor probably peaked, as declining agricultural employment in developed countries, transition countries, Latin America and China offset rising agricultural employment in other developing countries, most notably in sub-Saharan Africa and South Asia.

Table 16.3 - Productivity Indicators for World Agriculture

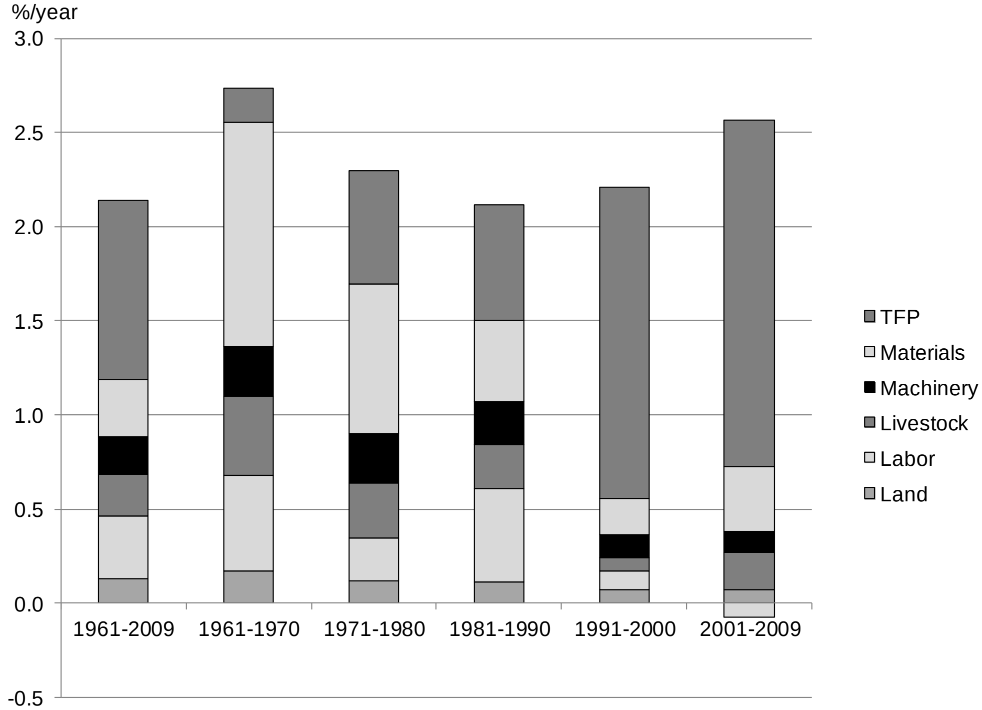
Period	Gross output	Total input	Total factor productivity	Output per Worker	Output per Hectare	Cereal Yield
			Average annual growth rate in percent			
1961-1970	2.74	2.55	0.18	1.13	2.45	2.88
1971-1980	2.30	1.70	0.60	1.58	2.09	2.08
1981-1990	2.12	1.50	0.62	0.62	1.75	1.88
1991-2000	2.21	0.55	1.65	2.00	2.16	1.57
2001-2009	2.49	0.65	1.84	2.80	2.64	1.80
1971-1990	2.25	1.53	0.72	1.11	1.97	2.25
1991-2009	2.29	0.70	1.59	1.97	2.27	1.42
1961-2009	2.23	1.28	0.95	1.19	2.00	1.99

Gross output: FAO gross production value in constant 2004-2006 international dollars. Total input: Author's aggregation of agricultural land, labor, capital and material inputs (see text). TFP: The difference between output growth and total input growth, based on author's estimation. Output per worker: FAO gross production value divided by number of persons working in agriculture. Output per hectare: FAO gross production value divided by total arable land and permanent pasture. Cereal yield: Global production of maize, rice and wheat divided by area harvested of these crops. The average annual growth rate in series Y is found by regressing the natural log of Y against time, i.e., the parameter B in $\ln(Y) = A + Bt$.

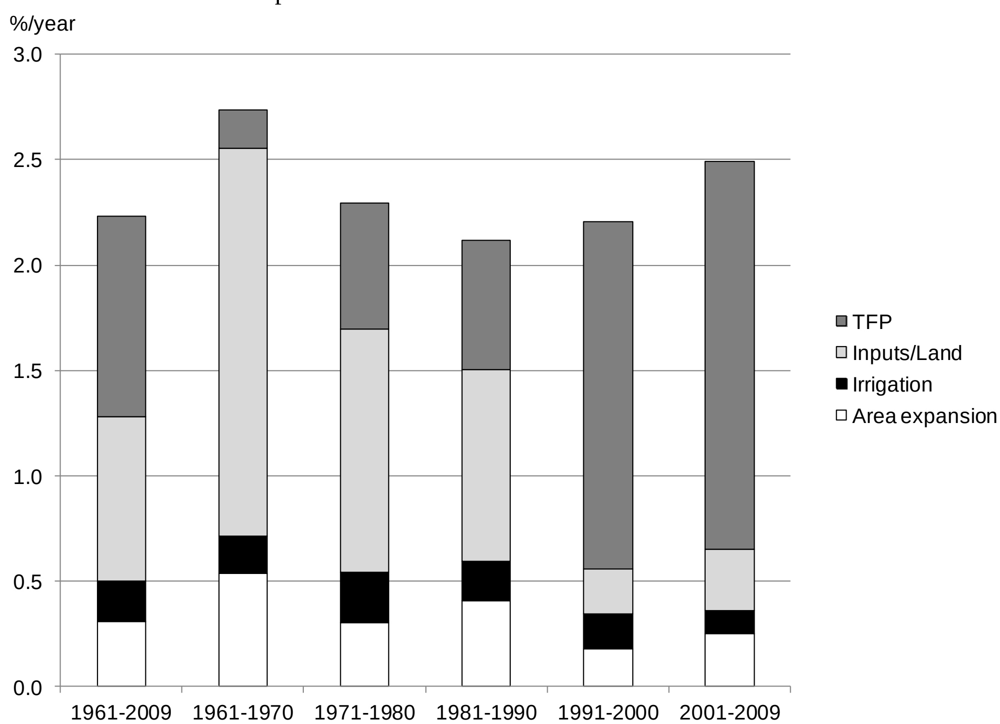
Figure 16.2 Panel B decomposes the sources of global agricultural growth slightly differently. Instead of by input cost, it shows the relative contribution of land and irrigation expansion, input intensification on land, and TFP (see equations 16.6 and 6.10). The rate of expansion in natural resources (land and water) has diminished over time while the rate of growth in resource yield has risen. However, the source of yield gain has shifted markedly from input intensification to improvement in TFP.

Figure 16.2 Sources of Global Agricultural Growth

Panel A. Input Cost Decomposition



Panel B. Resource Decomposition



The height of the bar shows the average annual growth rate in gross agricultural output during the period specified. The shaded components of the bar show the contribution of that component to total output growth.

Table 16.4 - Agricultural Output and Productivity Growth for Global Regions by Decade

Region	Agricultural Output Growth (annual %)					Agricultural TFP Growth (annual %)				
	1961-70	1971-80	1981-90	1991-00	2001-09	1961-70	1971-80	1981-90	1991-00	2001-09
All Developing Countries	**3.15**	**2.97**	**3.43**	**3.64**	**3.34**	**0.69**	**0.93**	**1.12**	**2.22**	**2.21**
Sub-Saharan Africa	2.95	1.19	2.82	3.05	2.69	0.17	-0.05	0.76	0.99	0.51
Latin America & Caribbean	3.05	3.31	2.26	3.14	3.41	0.84	1.21	0.99	**2.30**	**2.74**
Caribbean	1.70	1.97	0.68	-0.73	-0.18	-1.00	0.57	-0.26	-0.55	-0.16
Central America	4.63	3.72	1.36	2.95	2.24	2.83	1.95	-1.69	3.05	2.33
Andean countries	2.97	2.75	2.77	3.08	3.19	1.49	1.18	0.55	2.12	2.60
Northeast (Brazil, mainly)	3.56	3.86	3.41	3.65	4.44	0.25	0.60	3.02	2.62	4.03
Southern Cone	1.80	2.87	1.13	3.15	2.79	0.58	2.56	-0.82	1.61	1.29
Asia (except West Asia)	3.26	3.10	3.67	3.78	3.41	0.91	1.17	1.42	**2.73**	**2.78**
Northeast (China, mainly)	4.79	3.32	4.49	5.17	3.39	0.94	0.67	1.71	4.10	3.05
Southeast Asia	2.63	3.92	3.31	2.89	4.45	0.57	2.10	0.54	1.69	3.29
South Asia	2.02	2.66	3.31	2.65	3.32	0.63	0.86	1.31	1.22	1.96
West Asia & North Africa	2.87	3.05	3.64	2.82	2.35	1.40	1.66	1.63	1.74	1.88
North Africa	2.62	1.58	4.53	3.34	3.57	1.32	0.48	3.09	2.03	3.04
West Asia	2.98	3.65	3.29	2.60	1.77	1.21	2.21	0.95	1.70	1.34
Oceania	2.53	2.34	1.58	2.07	2.29	-0.14	0.47	-0.73	0.54	1.33
All Developed Countries	**2.05**	**1.93**	**0.72**	**1.37**	**0.58**	**0.99**	**1.64**	**1.36**	**2.23**	**2.44**
United States & Canada	2.06	2.29	0.68	1.96	1.41	1.25	1.67	1.31	2.18	2.24
Europe (except FSU)	1.96	1.60	0.42	0.24	-0.16	0.58	1.44	1.43	1.25	1.98
Europe, Northwest	1.56	1.36	0.51	0.34	-0.09	0.85	1.48	1.55	1.80	2.75
Europe, Southern	2.11	1.96	0.69	1.32	-0.42	1.97	2.03	1.30	2.42	3.04
Australia & New Zealand	2.90	1.68	1.48	3.21	-0.22	0.72	1.53	1.35	2.62	1.09
NE Asia, developed	3.31	2.23	1.23	0.18	-0.24	2.34	2.46	1.74	2.23	2.07
Transition Countries	**3.27**	**1.32**	**0.85**	**-3.51**	**1.96**	**0.57**	**-0.11**	**0.58**	**0.78**	**2.28**
Eastern Europe	2.67	1.73	-0.04	-1.35	0.04	0.54	0.59	0.81	0.79	0.78
Former Soviet Union (FSU)	3.59	1.10	1.30	-4.69	2.96	0.53	-0.51	0.63	0.59	3.29
Baltic *	3.56	0.93	1.09	-6.01	2.10	2.11	-0.49	0.58	0.82	2.20
Central Asia & Caucasus *	3.41	4.71	0.56	0.08	4.33	-0.36	2.02	-0.89	0.65	2.45
Eastern Europe FSU *	3.16	0.76	1.39	-5.39	2.70	0.89	-0.85	0.86	0.92	4.00
World	**2.74**	**2.30**	**2.12**	**2.21**	**2.49**	**0.18**	**0.60**	**0.62**	**1.65**	**1.84**

* Data for former Soviet republics covers 1965-2009 only. The average annual growth rate in series Y is found by regressing the natural log of Y against time, i.e., the parameter B in $\ln(Y) = A + Bt$.

Source: Author's estimates. See Table 3 for list of countries in each regional group.

The estimates of global agricultural output and TFP growth are disaggregated among regions and sub-regions in Table 16.4 (results for specific countries are given in Appendix Table A16.2). The regional results reveal that the global trend is hardly uniform, with three general patterns evident:

1. ***In developed regions***, total agricultural inputs have been declining since the 1980s (output growth is less than TFP growth) and at an increasing rate; TFP growth offset the declining resource base to keep output from falling and has remained robust (above 1.5% per year in all regions except Oceania (Australia & New Zealand).
2. ***In developing regions***, productivity growth doubled between the 1960s-1980s and the 1990s-2000s, from less than 1% to over 2% per year. Input growth has been slowing each decade but still expanding enough to keep output growing at over 3% annually for each of the last three decades. Two large developing countries in particular, China and Brazil, have sustained exceptionally high TFP growth. Several other developing regions, including Southeast Asia, North Africa, Central America and the Andean region, also registered accelerated TFP growth in the 1990s or 2000s. The major exception is the developing countries of Sub-Saharan Africa where long-run TFP growth remained below 1% per year.
3. ***In transition countries***, the dissolution of the Soviet Union in 1991 imparted a major shock to agriculture as these countries made a transition from centrally-planned to market-oriented economies. In the 1990s, agricultural resources sharply contracted and output fell. Total agricultural inputs were still declining in 2001-09 but at a much slower rate than during 1991-2000. Productivity growth, which was minimal during the USSR era, took off in 2001-09. As a result, output growth again turned positive. However, gross agricultural output in 2009 was below Soviet-era levels in every region except Central Asia & Caucasia (CAC).

The strong and sustained productivity growth described here is broadly consistent with results of the detailed country and regional case studies presented in the other chapters of this volume. Among industrialized countries, agricultural TFP growth has remained at historical levels in the United States (Wang *et al*, Chapter 2), Canada (Cahill *et al*, Chapter 3), and western Europe (Wang *et al*, Chapter 5), but has fallen in Australia (Zhao *et al*, Chapter 4) and South Africa (Liebenberg, Chapter 14). The case studies found evidence that these patterns were correlated with the rate of growth in public investments in agriculture, particularly in research and development.

For transition countries, Swinnen *et al* (Chapter 6) provide an explanation for the renewed but uneven recovery of agricultural productivity in this region. They find it to be related to the pace of economic reforms implemented since the collapse of the Soviet Union, especially in the institutions governing land and labor relations and in the functioning of agricultural markets. As what happened earlier (and more smoothly) in China, moving from collective and state-owned corporate farming responding to state mandates to privately- (especially family-) operated farms responding to market incentives brought significant gains in efficiency (Rozelle and Swinnen, 2004). Once the initial gains from institutional reform were realized, China was able to sustain productivity growth through technological change (Tong *et al*, Chapter 8). Whether this pattern will also be followed in the countries of the former Soviet Union and Eastern Europe remains to be seen; it will likely depend on their policies governing the development of and access to new agricultural technology.

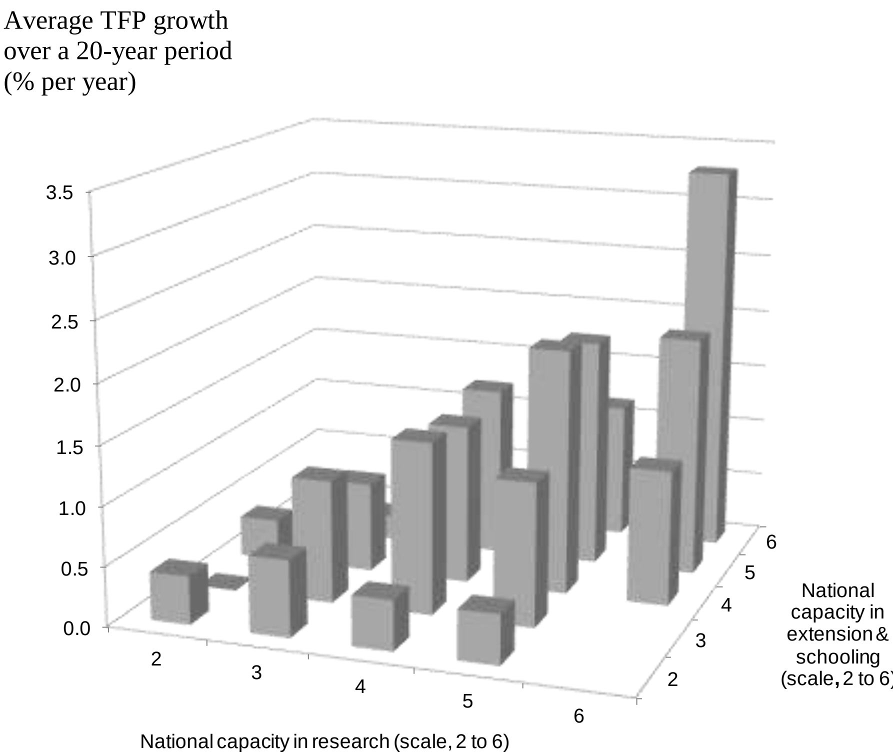
For developing countries, the robust growth in agricultural TFP over the past one to three decades measured for Brazil (Gasques *et al*, Chapter 7), China (Tong *et al*, Chapter 8), and Indonesia (Rada and Fuglie, Chapter 10) is consistent with the results presented here, as is the result of relatively low TFP growth for sub-Saharan Africa (Fuglie and Rada, Chapter 12; Nin-Pratt and Yu, Chapter 13). The Indian productivity trend reported by Binswanger-Mkhize and d'Souza (Chapter 9) are drawn directly from my estimates. India represents a middle case of moderate TFP growth of about 1.3%/year since the 1970s-1990s, although in 2001-2009 it appeared to also accelerate to over 2% per year. Binswanger-Mkhize and d'Souza argue that India will need to achieve strong agricultural TFP growth if the sector is to be a major source of employment generation and poverty reduction for the country. Finally, for Thailand, my results track the TFP growth estimates of Suphannachart and Warr (Chapter 11) closely for 1961-1993 but then diverge. For the years after 1993 I find continued TFP improvement while they find falling TFP. The principal reason for this difference appears to be a higher input cost share that Suphannachart and Warr give to agricultural capital stock, which in turn results in a higher rate of growth in total inputs. As Butzer *et al* explain in Chapter 15, internationally comparable measures of capital stock and the cost of capital services have been lacking for agriculture, and this can confound analyses of productivity and growth. More complete and comparable data on agricultural capital is one of the most pressing needs to improve our ability to assess long-term trends in global agricultural productivity.

16.3.2 Technology Capital and TFP Growth

What explains the apparent acceleration in agricultural TFP growth in developing countries, or at least in many of them? The case studies in this volume identified institutional and economic reforms as an important source of productivity growth, at least in the medium term, and research and development for sustaining productivity growth over the long term. The model described above on technology capital and TFP growth examines this question for a group of 87 developing countries over a 40-year period.

Table 16.5 shows the econometric estimates of equation (16.7), where long-run average TFP growth rates for 87 developing countries are regressed against combinations of innovation-invention and technology-mastery capitals. The regression coefficients in Table 16.5 are arrayed in a matrix corresponding to the $\mathbb{II}$ and $\mathbb{TM}$ combinations they refer to. The coefficient estimates reflect the average annual TFP growth rate (in percent) for all countries having technology capital in that $\mathbb{II}$ and $\mathbb{TM}$ class. The numbers in parentheses below the coefficients indicate the number of observations that fell in that class. For example, there were 18 countries that were characterized as having little or no technology capital ($\mathbb{II}$ class = 2 and $\mathbb{TM}$ class = 2). These countries as a group achieved a mean annual TFP growth of 0.41 percent, which was not significantly different from zero. At the other end of the technology capital scale there were two countries with $\mathbb{II}$ class = 6 and $\mathbb{TM}$ class = 6, and these achieved an average annual TFP growth rate of 3.29 percent. These countries are Brazil and China, large countries that have invested heavily in agricultural research and extension. Figure 16.3 plots out these coefficients visually. There is a clear progression to higher TFP growth as countries increase $\mathbb{II}$ and $\mathbb{TM}$ technology capital. However, countries needed a minimal capacity in both research and extension-schooling in order to sustain significant productivity growth. When either $\mathbb{II}$ capital or $\mathbb{TM}$ capital were at very low levels (class 2), mean TFP growth rates were not significantly different from zero. With one exception, technology capitals of (II,TM) combinations of (3,3) and higher were all associated with positive and significant TFP growth. The exception is (II,TM) class (3,5), which consists of only two countries – Panama in 1971-1990 and Zimbabwe in 1991-2009. Both of these countries suffered from political instability and poor macroeconomic performance over these periods, which may account for their low agricultural productivity growth (0.21% per year on average) despite significant levels of extension-schooling and some research capacity.

Figure 16.3. Technology Capital and Agricultural TFP Growth



Source: Author's estimates.

The F-statistic tests reported in the final column and row of Table 16.5 examine the marginal effects of research and extension holding the other fixed. Casual observation indicates that TFP growth rates tended to rise at higher levels of either II or TM capital (holding the other fixed), but the F-statistic tests the hypothesis that all of the row (or column) coefficients are equal. In other words, it tests the hypothesis that there was no significant increase in TFP growth with a marginal increase in one of the kinds of technology capital. Neither II capital (research) or TM capital (extension and schooling) was effective at raising agricultural TFP growth without at least a minimal capacity in the other. But in the case of research, TFP growth rose significantly with marginal increases in II capital when TM capital was held constant at level 3, 4 and 6 (TFP growth also rose when TM capital was held fixed at 5 but the increase in TFP growth was not statistically significant). On the other hand, in no case did a marginal increase in TM capital significantly increase TFP growth when II capital remained constant. In other words, agricultural extension and schooling do not appear to be substitutes for research and development capacity.

Improved capacity to invent and adapt new technology to country-specific conditions was a requisite for sustaining long-run TFP growth in agriculture.

What the above estimates demonstrate is that countries with higher levels of II and TM capitals experienced more rapid agricultural TFP growth. But it could be that unobserved characteristic of the countries may be influencing both variables, undermining casual inference. The difference-in-differences model (equation 16.8), on the other hand, tests whether countries that *increased* their II or TM capitals between 1970-75 and 1990-95 also saw an *increase* in their average TFP growth rates between 1971-90 and 1991-09. The results find that countries that increased their II capital between 1970-75 and 1990-95 achieved more rapid agricultural TFP growth in the decades following, while an increase in TM capital did not. Increasing II capital by one unit on the index scale raised the average annual TFP growth rate by 0.46 percentage points (Table 16.6). The evidence is strongest for Latin America, where an increase in II capital was associated with an increase in the TFP growth rate of 0.76 percentage points. The effect of II capital on TFP growth in Asian countries was also positive and significant (0.48 percentage points), while for sub-Saharan Africa it was positive but not statistically significant. The evidence presented earlier in this volume (Fuglie and Rada, Chapter 12; Nin-Pratt and Yu, Chapter 13) provide insights into why research capacity in sub-Saharan Africa did not seem to have had much impact on growth in the region: small countries may not have been able to achieve sufficient scale in their national R&D systems, economic and trade policies have reduced incentives to agricultural producers, the AIDS/HIV epidemic has reduced the health of the population, civil disturbances and war have been widespread, and poor infrastructure reduces access to markets.

Table 16.5. Technology capital and agricultural TFP growth

Technology Mastery (TM) class (Agricultural extension + schooling)	Invention-Innovation (II) class (Agricultural research + industry R&D): 2	3	4	5	6	Marginal effect of II holding TM fixed
	coefficients show average annual TFP growth rate in percent (number in parenthesis is number of observations with II-TM combination)					
2	0.41 (n=18)	0.64 (n=14)	0.42 (n=8)	0.42 (n=1)		F(3,155)= 0.10 ns
3	-0.01 (n=9)	1.03 *** (n=25)	1.44 *** (n=15)	1.20 * (n=2)		F(3,155)= 2.48 ^
4	0.35 (n=4)	0.76 ** (n=12)	1.34 *** (n=29)	2.07 *** (n=8)	1.14 * (n=2)	F(4,155)= 1.79 ^
5		0.21 (n=2)	1.44 ** (n=7)	1.93 *** (n=9)	2.03 ** (n=2)	F(3,155)= 1.10 ns
6				1.15 ** (n=5)	3.29 *** (n=2)	F(1,155)= 3.99 ^^
F-test of marginal effect of TM holding II fixed	F(2,155)= 0.32 ns	F(3,155)= 0.48 ns	F(3,155)= 1.33 ns	F(4,155)= 0.79 ns	F(2,155)= 1.42 ns	

*,**,*** indicate coefficients are significant from zero at 10%, 5%, and 1% significance level.

^,^^ indicate rejection of hypothesis that all coefficients in row or column are equal at 10% and 5% significance level and "ns" indicates cannot reject hypothesis of equal coefficients.

Data sample: 87 developing countries over two periods

Number of obs =	174	F(18, 155) =	2.06	Prob > F =	0.010
R-squared =	0.193	Adj R-sqr =	0.100	Root MSE =	0.013

Source: Author's estimates of equation (16.7).

Table 16.6. Difference-in-Difference Model of Technology Capital and TFP Growth

Dependent variable: Change in TFP growth rate between 1971-1990 and 1991-2009
Independent variables: Change in **II** and **TM** capitals between 1970/75 and 1990/95

Model	Obs.	Coefficients (t-ratios in parenthesis) II		TM		R-squared	Adj R-sq
All Countries	87	0.458	**	0.162	ns	0.111	0.090
		(2.00)		(0.78)			
LAC	22	0.764	**	0.498	ns	0.393	0.332
		(2.11)		(1.41)			
Asia	28	0.480	*	-0.176	ns	0.034	-0.040
		(0.79)		(-0.41)			
SSA	37	0.226	ns	0.328	ns	0.05	-0.004
		(0.66)		(0.79)			

*,**,*** = significant at 10%, 5% and 1% level, respectively. ns = not significant.
LAC = Latin America & Caribbean; Asia includes developing countries in East, South and West Asia. SSA = sub-Saharan Africa.
Source: Author's estimates of equation (16.8) in text.

16.4 Conclusions

The framework outlined in this chapter provides a means for viewing agricultural productivity trends at the global level. It draws together the major available data series on national agricultural outputs and inputs to estimate growth in TFP in a consistent fashion by country, region and the world as a whole. The principal innovations introduced in this chapter compared with my earlier work using this approach (Fuglie, 2008, 2010b) are (i) chain-indexing the total input index using variable factor shares, (ii) decomposing growth into *input cost* and *natural resource* contributions to total growth and (iii) using a more complete accounting of farm machinery inputs and. Nonetheless, it is likely that the machinery input series is still underestimating actual growth in fixed capital (see Butzer *et al*, Chapter 15). Another potential shortcoming is that fertilizer use trends may be a poor proxy for growth in total material inputs. It would be especially helpful if consistent series on animal feed inputs could be developed (possibly from the FAO commodity balance sheets). Any under-accounting of growth in capital, material, or other inputs implies an over-accounting of the growth in TFP. Despite these data shortcomings, where comparisons are possible the TFP indexes developed here generally show a good fit with TFP indexes constructed from more detailed, national-level data.

The empirical analysis examined global agricultural growth over 1961-2009. The major empirical finding is that based on these measures there does not appear to be a slowdown in sector-wide global agricultural productivity growth. If anything, the growth rate in global agricultural TFP accelerated, in no small part because of rapid productivity gains achieved by developing countries, led by Brazil and China, and more recently because of a recovery of agricultural growth in the countries of the former Soviet Union. However, the results do show clear evidence of a slowdown in the growth in agricultural investment: the global agricultural resource base is still expanding but at a much slower rate than in the past. These two trends—accelerating TFP growth and decelerating input growth—have largely offset each other to keep the real output of global agriculture growing at over 2% per year since the 1970s. Agricultural producers have substituted productivity for natural and material resources as the primary means of raising agricultural supply. This finding has important implications for the appropriate supply-side policy response to the recent rise in real agricultural prices and the future potential to raise agricultural supply.

One implication is that we should be sanguine about the prospects for global agriculture to respond to the recent commodity price rises by increasing supply in the short run. If TFP were slowing down, it would likely take several years for policy responses to influence this trend. The principal policy lever to increase TFP growth is to increase spending on agricultural research, but there are long time lags between research investments and productivity growth. But the main trend identified here is a slowdown in the rate of growth in agricultural inputs. This is at least in part a consequence of a long period of declining real prices facing producers, who then found better opportunities for their capital outside of agriculture. It was also in part a consequence of the institutional changes in the countries of the former Soviet bloc that precipitated a rapid exit of resources from agriculture in that region. The incentives afforded by the current high commodity prices and a resumption of agricultural growth in the former Soviet republics should positively affect the rate of agricultural capital formation at the global level. So long as TFP growth continues at its recent historical pace, this should lead to an increased rate of real output growth in global agriculture in a relatively short period of time.

The evidence presented in this chapter suggests that there has been a convergence in agricultural productivity growth across major world regions, with TFP growth in developed, developing and transition country regions all growing at or slightly about 2% per year at least since the turn of the Century. This is in marked contrast with previous decades, in which productivity growth in developed countries was markedly higher than elsewhere (a result also demonstrated by Hayami and Ruttan (1985) and Craig, Pardey, and Roseboom (1997), who found developing countries were falling further behind developed countries in agricultural land and labor productivity). Nonetheless, it remains true that many countries have not been able to achieve or sustain productivity growth in agriculture and as a consequence suffer from high levels of poverty and food insecurity. This has not contributed to a *slowdown* in global agricultural TFP growth because their growth rates were never high to begin with. But this certainly has led to agriculture performing below its potential and has kept these countries poor. The largest group of countries in this low-growth category is in Sub-Saharan Africa, but also included are several countries in Latin America (notably Bolivia, Panama, Paraguay and several Caribbean states) and in the Asia-Pacific region.

Finally, there is evidence that agricultural productivity growth has been uneven across commodities. However, our ability to assess productivity growth at the commodity level is limited mainly to examining harvest yield trends since labor and capital inputs tend to be shared across multiple commodities in the production process. Thus, the slowing of growth in cereal yield (World Bank, 2007; Alston, Beddow and Pardey, 2009) does raise concerns that there is underinvestment (or low returns) to research directed at these commodities. But even here the picture is uneven, for decomposing cereal yield trends reveal that the slowdown affected primarily wheat and rice yields, with corn yield growth continuing to perform well after 1990. It is possible that the relatively strong performance in corn yield growth is due to the historically higher level of investment in research and development (R&D) for this crop because of the strong private-sector interest in breeding for hybrid corn (Fuglie *et al*, 1996). In any case, the implication for R&D policy is quite different than if a sector-wide productivity slowdown were occurring. Rather than comprehensive changes to agricultural R&D or investment policies, the uneven performance within the agricultural sector suggests a more selective approach that requires a clear understanding of the causes of low productivity growth in particular commodities and countries.

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Appendix to Chapter 16

Table A16.1 - Agricultural Input Cost Shares

Source Study	Input	Input Cost Shares 1961-70	1971-80	1981-90	1991-00	2001-10	Input shares applied to
INDUSTRIALIZED COUNTRIES							
South Africa	Labor	0.232	0.210	0.166	0.161	*0.161*	
	Land	0.129	0.143	0.169	0.144	*0.144*	
Schimmelpfennig *et al* (2000)	Livestock	0.252	0.230	0.237	0.239	*0.239*	South Africa
	Fixed capital	0.141	0.138	0.154	0.182	*0.182*	
	Materials	0.246	0.279	0.275	0.274	*0.274*	
USA	Labor	0.235	0.184	0.171	0.221	0.226	
	Land	0.203	0.225	0.188	0.176	0.152	
Economic Research Service (a), based on Ball (1985)	Livestock	0.291	0.301	0.281	0.250	0.257	USA
	Fixed capital	0.128	0.134	0.180	0.129	0.131	
	Materials	0.143	0.156	0.180	0.224	0.234	
Canada	Labor	0.345	0.406	0.303	0.431	0.349	
	Land	0.035	0.023	0.022	0.016	0.016	
Cahill, Phillips and Rich (2012)	Livestock	0.251	0.213	0.234	0.204	0.222	Canada
	Fixed capital	0.146	0.147	0.162	0.087	0.085	
	Materials	0.223	0.211	0.279	0.262	0.328	
Australia	Labor	*0.176*	0.176	0.093	0.089	0.098	
Zhao, Sheng and Grey (2012) with Butzer, Mundlak and Larson's (2012) decomposition of total capital stock	Land	*0.348*	0.348	0.600	0.653	0.539	
	Livestock	*0.052*	0.052	0.019	0.011	0.016	Australia and New Zealand
	Fixed capital	*0.222*	0.222	0.156	0.114	0.162	
	Materials	*0.200*	0.200	0.131	0.133	0.186	
Japan	Labor	0.384	0.335	0.309	0.308	0.307	
	Land	0.322	0.291	0.279	0.286	0.278	
Van der Meer and Yamada (1999)	Livestock	0.128	0.123	0.134	0.131	0.130	Japan
	Fixed capital	0.075	0.136	0.157	0.153	0.162	
	Materials	0.091	0.114	0.121	0.122	0.122	
Korea-Taiwan	Labor	0.372	0.558	0.349	0.208	0.156	
1961-70 is average for Korea and Taiwan from Hayami, Ruttan & Southworth (1979); 1970+ from Kwon (2010) using Korea data	Land	0.419	0.227	0.392	0.506	0.519	
	Livestock	0.067	0.004	0.009	0.010	0.012	South Korea and Taiwan
	Fixed capital	0.013	0.016	0.040	0.080	0.122	
	Materials	0.129	0.194	0.210	0.196	0.191	
United Kingdom	Labor	0.327	0.164	0.136	0.137	*0.137*	
	Land	0.084	0.126	0.179	0.216	*0.216*	
Thirtle, Piesse and Schimmelpfennig (2008)	Livestock	0.251	0.333	0.284	0.235	*0.235*	United Kingdom
	Fixed capital	0.183	0.199	0.202	0.204	*0.204*	
	Materials	0.155	0.178	0.199	0.209	*0.209*	
Europe, Northern except UK	Labor	*0.334*	0.334	0.244	0.235	0.220	
	Land	*0.040*	0.040	0.074	0.079	0.069	
Ball *et al* (2010); capital decomposition from Butzer, Mundlak and Larson (2012)	Livestock	*0.261*	0.020	0.024	0.017	0.013	Northern Europe except United Kingdom
	Fixed capital	*0.073*	0.073	0.104	0.134	0.134	
	Materials	*0.292*	0.533	0.554	0.535	0.564	
Europe, Southern	Labor	*0.577*	0.577	0.450	0.404	0.469	
	Land	*0.085*	0.085	0.124	0.154	0.096	
Ball *et al* (2010); capital decomposition from Butzer, Mundlak and Larson (2012)	Livestock	*0.016*	0.016	0.018	0.014	0.010	Southern Europe
	Fixed capital	*0.059*	0.059	0.076	0.114	0.105	
	Materials	*0.263*	0.263	0.331	0.313	0.319	

Table 16.2 (continued). Agricultural Input Cost Shares

	Input Factor	Factor Shares					Input shares applied to
		1961-70	1971-80	1981-90	1991-00	2001-10	
DEVELOPING COUNTRIES & REGIONS							
Sub-Saharan Africa	Labor	0.248	0.248	0.248	0.248	0.248	Sub Saharan Africa
	Land	0.315	0.315	0.315	0.315	0.315	
Fuglie (2011)	Livestock	0.357	0.357	0.357	0.357	0.357	
	Fixed capital	0.024	0.024	0.024	0.024	0.024	
	Materials	0.055	0.055	0.055	0.055	0.055	
Mexico	Labor	0.256	0.239	0.119	0.115	*0.115*	Central America & Caribbean
	Land	0.489	0.344	0.179	0.225	*0.225*	
Fernandez-Cornejo and Shumway (1997)	Livestock	0.118	0.221	0.371	0.353	*0.353*	
	Fixed capital	0.089	0.162	0.315	0.263	*0.263*	
	Materials	0.048	0.035	0.017	0.045	*0.045*	
Brazil	Labor	0.434	0.434	0.443	0.415	0.373	South America, North Africa and West Asia
Estimated provided by Nicholas Rada, unpublished, calculated from Brazilian Agricultural Census' 1970, 1985, 1996, 2006 (IBGE)	Land	0.342	0.342	0.159	0.115	0.083	
	Livestock	0.126	0.126	0.168	0.181	0.129	
	Fixed capital	0.071	0.071	0.110	0.177	0.161	
	Materials	0.027	0.027	0.120	0.112	0.255	
China	Labor	0.443	0.396	0.413	0.333	*0.333*	China, Mongolia, and North Korea
	Land	0.261	0.208	0.177	0.255	*0.255*	
Fan and Zhang (2002)	Livestock	0.228	0.247	0.230	0.206	*0.206*	
	Fixed capital	0.021	0.070	0.087	0.074	*0.074*	
	Materials	0.048	0.078	0.093	0.132	*0.132*	
India	Labor	0.406	0.419	0.564	*0.564*	*0.564*	South Asia
	Land	0.314	0.210	0.173	*0.173*	*0.173*	
Evenson, Pray and Rosegrant (1999)	Livestock	0.263	0.319	0.173	*0.173*	*0.173*	
	Fixed capital	0.003	0.010	0.024	*0.024*	*0.024*	
	Materials	0.014	0.042	0.066	*0.066*	*0.066*	
Indonesia	Labor	0.370	0.538	0.476	0.388	0.392	Southeast Asia and developing countries in Oceania
	Land	0.219	0.195	0.188	0.306	0.329	
Fuglie (2010a)	Livestock	0.360	0.199	0.278	0.251	0.217	
	Fixed capital	0.018	0.020	0.004	0.010	0.015	
	Materials	0.033	0.048	0.054	0.045	0.046	
TRANSITION COUNTRIES & REGIONS							
USSR, European	Labor	0.104	0.104	0.104	0.190	0.190	European states of the former Soviet Union
	Land	0.257	0.257	0.257	0.230	0.230	
Lerman *et al* (2003) for 1965-1990. Cungu and Swinnen (2003) for 1992+	Livestock	0.453	0.453	0.453	0.420	0.420	
	Fixed capital	0.043	0.043	0.043	0.090	0.090	
	Materials	0.143	0.143	0.143	0.070	0.070	
USSR, Asia	Labor	0.194	0.194	0.194	0.190	0.190	Asian states of the former Soviet Union
	Land	0.210	0.210	0.210	0.230	0.230	
Lerman *et al* (2003) for 1965-1990. Cungu and Swinnen (2003) for 1992+	Livestock	0.104	0.104	0.104	0.420	0.420	
	Fixed capital	0.113	0.113	0.113	0.090	0.090	
	Materials	0.379	0.379	0.379	0.070	0.070	

In some cases, studies reports cost shares of animal feed or other farm-supplied inputs. This has been included with the cost share of livestock capital. Cost shares in italics are extrapolations using estimates from the nearest period available. When studies did not break out fixed capital from livestock capital, I used average capital component shares for high-income or middle & low-income countries reported by Butzer *et al* in Chapter 15 of this volume (see Table 15.3).

Source: Compiled by author from sources listed. Eldon Ball, Shenggen Fan, Jorge Fernandez-Cornejo, Oh-Sang Kwon, Nicholas Rada, David Schimmelpfennig and Colin Thirtle kindly provided additional, unpublished data.

Table A16.2 - Agricultural Output and Productivity Growth by Country

Country	Region	Agricultural Output						Agricultural TFP				
		Avg 2006-09	1961-70	1971-80	1981-90	1991-00	2001-09	1961-70	1971-80	1981-90	1991-00	2001-09
Sub-Saharan Africa		Million $					Average annual growth (%)					
Cameroon	Central	3.71	3.89	1.51	2.05	3.20	3.27	-0.06	-1.58	0.79	1.28	2.32
C. African Rep.	Central	0.87	2.99	2.16	2.07	3.80	2.06	-1.55	-0.35	1.46	1.78	-0.04
Congo	Central	0.34	2.57	1.11	1.39	3.26	3.44	-0.78	0.18	0.01	1.39	3.06
Congo, DR	Central	3.67	1.76	1.58	3.07	-2.65	-0.05	-1.09	-0.29	0.69	-0.31	-1.29
Gabon	Central	0.25	1.67	3.42	2.39	1.83	1.30	-0.31	-1.58	-0.75	1.64	0.19
Burundi	Eastern	1.07	2.23	0.83	3.02	-1.38	-1.28	-1.40	-1.33	0.53	0.28	-4.19
Kenya	Eastern	6.10	2.81	3.85	4.34	1.23	3.43	-0.29	1.72	0.71	0.66	1.98
Rwanda	Eastern	1.62	4.69	4.09	1.47	0.63	4.00	0.24	2.53	-0.41	0.51	-2.10
Tanzania	Eastern	6.53	3.18	3.43	2.24	1.87	4.14	-0.50	0.82	0.54	0.38	1.03
Uganda	Eastern	5.45	5.44	-1.63	2.81	2.70	0.84	2.55	-0.02	1.78	-0.06	-1.90
Ethiopia, former	Horn	8.00	2.03	1.36	0.66	3.10	4.82	-1.09	1.23	-1.17	-0.12	1.38
Somalia	Horn	1.59	3.69	2.49	0.91	1.94	0.84	0.40	1.30	-0.32	1.55	0.41
Sudan	Horn	8.06	2.66	3.05	0.79	4.85	1.41	-1.12	1.07	0.54	1.94	0.04
Burkina Faso	Sahel	2.20	3.09	2.10	6.40	4.08	2.67	-0.88	-0.85	1.76	1.03	-2.16
Chad	Sahel	1.42	0.83	1.27	2.87	4.00	1.99	-1.89	0.88	1.02	0.33	-0.13
Gambia	Sahel	0.12	2.54	-2.88	-0.09	3.48	1.90	-1.49	-4.23	-1.84	1.25	-2.03
Mali	Sahel	2.61	3.00	3.45	3.00	3.24	4.95	-1.53	1.95	1.82	1.37	2.39
Mauritania	Sahel	0.45	1.60	1.53	1.74	1.89	1.85	-0.95	0.53	-0.52	0.39	0.57
Niger	Sahel	2.81	2.86	3.82	0.78	5.31	6.16	-2.07	-0.21	0.52	2.33	3.31
Senegal	Sahel	1.20	-0.25	0.89	2.39	1.82	4.04	-3.22	-0.14	0.96	-0.41	2.11
Angola	Southern	2.14	3.04	-4.64	1.14	4.76	6.82	-2.01	-4.76	-0.40	3.94	3.00
Botswana	Southern	0.25	3.52	-0.02	0.82	-1.28	3.33	2.07	-2.06	0.38	-4.37	2.52
Lesotho	Southern	0.12	1.69	0.86	0.61	1.45	-0.52	-0.31	0.77	-1.30	0.17	0.29
Madagascar	Southern	3.14	2.78	1.23	1.64	0.49	3.09	-0.52	-0.76	0.86	-0.19	0.85
Malawi	Southern	2.52	3.97	3.48	1.24	6.43	5.35	0.17	0.57	-0.24	5.17	1.32
Mauritius	Southern	0.25	1.64	0.31	0.99	0.25	-0.29	1.07	0.45	-0.31	-0.27	-0.38
Mozambique	Southern	1.99	3.00	-1.89	-0.98	6.77	1.60	0.25	-2.96	1.14	2.70	-0.03
Namibia	Southern	0.44	3.69	-1.82	0.85	-0.55	0.99	2.56	-1.92	-0.19	-2.29	0.75
Réunion	Southern	0.17	0.50	2.55	2.46	1.71	0.71	0.01	1.35	3.01	2.48	0.74
Swaziland	Southern	0.28	4.43	3.67	2.23	-0.63	1.43	3.20	2.23	0.32	-0.19	1.52
Zambia	Southern	1.16	3.47	2.27	4.51	1.48	4.13	0.67	1.24	0.77	1.22	2.17
Zimbabwe	Southern	1.53	4.09	1.46	2.37	3.30	-2.58	1.00	0.98	0.67	1.12	-1.65
Benin	Western	1.88	2.48	2.20	4.98	6.07	2.34	-1.48	1.82	2.51	1.91	2.93
Côte d'Ivoire	Western	5.96	4.81	4.64	3.55	3.82	1.59	0.19	-0.05	0.53	2.21	0.76
Ghana	Western	5.67	2.55	-2.64	5.08	5.23	4.00	-0.79	-3.55	3.99	1.79	1.21
Guinea	Western	1.90	1.96	1.43	2.46	3.33	3.23	0.10	0.60	1.58	-1.65	0.05
Guinea-Bissau	Western	0.25	-3.15	3.21	3.32	3.68	1.88	-2.72	-0.35	3.67	-0.24	0.36
Liberia	Western	0.41	4.30	1.80	-0.85	6.13	0.89	-0.36	-0.50	-0.73	3.10	-1.65
Sierra Leone	Western	0.63	2.92	1.35	1.76	-1.34	6.06	-0.75	-0.43	-0.08	1.29	2.24
Togo	Western	0.75	2.38	1.06	3.52	3.92	1.34	-1.28	-1.74	-2.16	0.97	-0.26
Nigeria (FAO data)	Nigeria	35.19	3.30	-0.85	6.34	4.22	1.96	-0.97	-2.36	2.51	3.11	0.48
Nigeria (alt. date)	Nigeria	30.02	3.02	-0.14	4.70	3.85	2.24	-1.32	-2.21	0.33	2.19	0.22

Country	Region	Agricultural Output						Agricultural TFP				
		Avg 2006-09	1961-70	1971-80	1981-90	1991-00	2001-09	1961-70	1971-80	1981-90	1991-00	2001-09
Latin American & Caribbean (LAC)		Million $	Average annual growth (%)									
Cuba	Caribbean	2.88	2.97	2.99	0.88	-1.77	-2.81	-1.51	1.19	-0.02	-0.73	-2.48
Dominican Republic	Caribbean	2.37	1.40	2.24	0.87	0.33	3.29	-0.30	0.70	-0.60	1.15	2.09
Haiti	Caribbean	1.00	2.01	1.48	-0.58	0.21	1.50	0.24	0.59	-0.66	-1.01	0.99
Jamaica	Caribbean	0.54	0.85	0.17	0.73	2.01	-0.06	1.44	-1.14	-0.15	2.10	3.05
Lesser Antilles	Caribbean	0.33	0.02	-0.57	1.41	-0.70	-2.99	-0.31	-1.08	1.70	-1.13	-0.90
Puerto Rico (USA)	Caribbean	0.31	-2.48	-0.46	0.52	-3.01	-0.35	-0.71	1.80	0.82	-2.07	0.88
Trinidad and Tobago	Caribbean	0.17	2.07	-1.78	-0.81	0.46	1.40	1.30	-2.19	-0.95	0.05	1.42
Belize	C. America	0.17	8.40	4.70	2.60	4.80	0.92	5.03	2.86	-0.44	4.62	-0.20
Costa Rica	C. America	2.75	6.56	2.98	4.21	3.28	3.03	4.77	1.13	3.86	4.13	2.47
El Salvador	C. America	1.15	2.19	2.92	-0.23	1.33	2.58	0.63	1.23	-1.27	1.54	2.12
Guatemala	C. America	3.72	4.44	3.52	2.24	3.91	4.39	2.50	1.95	1.49	2.86	2.73
Honduras	C. America	1.92	6.51	1.95	1.13	1.50	4.29	2.98	-0.15	-0.51	1.34	1.94
Mexico	C. America	35.22	4.45	4.09	1.34	2.98	1.82	2.65	2.17	-1.98	3.19	2.19
Nicaragua	C. America	1.30	5.97	1.94	-2.94	4.49	3.69	2.44	-1.78	-4.26	2.69	2.88
Panama	C. America	0.93	5.44	1.98	1.02	0.80	1.47	2.57	0.46	0.55	-0.78	1.31
Bolivia	Andean	3.00	4.10	3.02	3.10	4.11	2.96	1.81	0.71	1.70	2.82	-0.47
Colombia	Andean	13.91	2.45	4.11	2.54	1.56	3.02	1.27	2.56	1.43	2.07	2.99
Ecuador	Andean	6.71	2.10	1.12	4.07	3.89	3.34	0.00	-0.18	2.27	1.18	3.55
Peru	Andean	7.75	2.73	0.17	2.16	5.86	4.37	0.85	-0.99	-0.02	3.11	3.46
Venezuela	Andean	6.47	5.09	3.63	2.70	2.65	2.15	3.69	2.57	-0.90	3.20	1.85
Brazil	Northeast	126.64	3.57	3.88	3.44	3.65	4.45	0.19	0.53	3.02	2.61	4.04
Guyana	Northeast	0.32	1.10	1.20	-2.61	4.80	-0.66	-0.04	0.36	-1.64	4.45	-0.60
Suriname	Northeast	0.11	7.59	4.40	0.40	-3.42	3.24	5.09	3.77	0.69	-4.63	1.01
Argentina	S. Cone	41.36	1.80	3.01	0.48	3.24	2.68	0.12	3.13	-0.97	1.45	1.22
Chile	S. Cone	7.75	1.80	2.76	3.44	3.48	2.17	1.70	2.20	1.09	1.71	2.58
Paraguay	S. Cone	4.24	3.20	4.66	4.98	1.79	3.49	0.98	0.63	1.59	-2.35	-1.24
Uruguay	S. Cone	3.60	1.07	0.37	0.54	2.89	4.53	0.87	0.28	0.60	2.03	3.30
West Asia and North Africa (WANA)												
Algeria	North Africa	5.27	-0.97	-0.50	4.67	2.32	4.20	-1.29	-0.93	3.07	0.72	4.12
Egypt	North Africa	21.55	3.16	1.99	4.14	4.57	3.57	1.30	1.41	2.71	2.82	2.76
Libya	North Africa	1.11	8.26	6.23	2.24	3.26	0.95	8.00	3.48	3.60	4.46	3.02
Morocco	North Africa	7.43	4.56	0.97	6.02	1.52	3.82	3.07	-0.71	4.14	0.58	4.11
Tunisia	North Africa	3.66	1.56	2.28	3.84	2.02	2.97	0.75	1.46	3.51	0.38	1.34
Iran	West Asia	24.85	3.93	3.95	4.73	3.86	2.41	2.42	2.65	1.41	2.40	0.73
Iraq	West Asia	2.72	3.90	2.17	2.51	1.47	-1.98	0.85	2.85	1.45	0.39	-0.23
Israel	West Asia	2.70	6.18	3.34	0.58	2.26	1.94	5.65	2.74	0.95	2.41	2.57
Jordan	West Asia	1.03	-6.60	2.86	6.42	2.01	3.81	-8.84	3.94	3.80	2.12	5.87
Kuwait	West Asia	0.20	5.26	7.32	5.19	11.34	3.39	-0.74	2.04	0.08	7.05	-0.23
Lebanon	West Asia	1.26	3.52	0.94	5.76	0.32	0.94	3.44	2.01	8.83	-1.43	3.83
Oman	West Asia	0.32	1.98	7.90	3.49	4.92	1.71	-1.29	2.40	-2.64	3.92	-2.25
Saudi Arabia	West Asia	3.55	3.09	5.65	11.22	0.93	2.80	0.06	1.68	6.35	2.12	5.12
Syria	West Asia	6.58	1.41	7.44	1.22	4.26	0.93	-0.19	6.15	-2.45	2.65	-0.12
Turkey	West Asia	33.97	2.82	3.23	2.54	1.69	1.58	0.75	1.54	0.99	1.50	1.78
United Arab Emirates	West Asia	0.70	4.65	9.97	7.48	13.91	-1.74	2.71	3.93	-0.51	8.20	-4.73
Yemen	West Asia	1.57	-0.40	3.63	3.54	3.66	4.97	-2.94	1.31	1.44	1.72	2.24

Country	Region	Agricultural Output						Agricultural TFP				
		Avg 2006-09	1961-70	1971-80	1981-90	1991-00	2001-09	1961-70	1971-80	1981-90	1991-00	2001-09
Asia & Oceania, developing (LDC)		Million $					Average annual growth (%)					
China	Northeast	487.20	4.87	3.30	4.53	5.28	3.41	0.93	0.60	1.69	4.16	2.83
Korea, DPR	Northeast	3.76	2.25	4.52	3.22	-3.13	0.84	0.34	1.30	1.47	0.50	1.34
Mongolia	Northeast	0.71	0.59	1.95	1.10	0.01	1.76	0.08	0.12	0.27	0.89	0.58
Cambodia	Southeast	3.08	2.67	-7.04	6.14	4.73	8.13	-0.93	-4.19	2.69	3.06	5.85
Indonesia	Southeast	53.20	2.71	3.34	4.64	1.87	4.86	1.75	1.40	0.59	0.99	3.68
Laos	Southeast	1.52	5.66	1.22	2.98	5.24	4.69	0.61	-0.88	0.96	2.74	2.21
Malaysia	Southeast	13.64	5.41	4.40	4.61	2.50	4.00	3.57	2.56	3.29	1.88	3.81
Myanmar	Southeast	18.14	1.40	4.24	0.34	4.90	7.40	-1.68	2.14	-0.32	2.60	5.97
Philippines	Southeast	20.12	2.64	5.08	1.62	2.43	3.46	-0.18	3.57	0.11	0.80	2.70
Thailand	Southeast	28.79	3.43	4.97	2.63	1.99	2.78	0.44	2.44	0.44	2.79	2.37
Timor Leste	Southeast	0.13	2.42	-1.84	1.80	-0.83	3.06	0.50	0.17	-0.64	-1.79	0.88
Viet Nam	Southeast	26.22	0.45	2.93	4.01	5.91	4.22	-0.68	1.62	1.05	3.08	2.44
Afghanistan	South	3.02	3.12	1.59	-2.41	3.79	2.08	1.30	0.58	-0.12	2.73	-1.83
Bangladesh	South	19.36	2.15	1.97	2.07	2.95	4.32	-0.30	0.39	-0.51	2.12	3.31
Bhutan	South	0.17	2.66	2.71	1.50	2.07	4.12	0.40	-0.22	-0.41	0.55	1.13
India	South	205.34	1.68	2.75	3.35	2.52	3.27	0.49	1.00	1.33	1.11	2.08
Nepal	South	4.63	1.46	1.86	4.70	2.82	2.61	-0.19	-1.22	2.34	0.19	2.49
Pakistan	South	35.87	4.26	2.78	4.78	3.24	3.34	1.90	0.16	3.21	1.19	0.59
Sri Lanka	South	2.61	2.67	3.26	-0.59	1.07	2.33	0.93	2.30	-1.64	1.32	1.17
Fiji	Oceania, LDC	0.22	2.45	2.74	1.25	-0.74	-0.89	0.17	0.17	-1.21	-1.49	-0.36
Papua New Guinea	Oceania, LDC	2.57	2.97	2.33	2.12	2.46	2.51	-1.08	0.59	-0.06	0.52	1.00
Polynesia	Oceania, LDC	0.12	0.15	0.44	-1.94	0.94	1.73	-1.25	-2.54	-2.21	0.19	2.71
Solomon Islands	Oceania, LDC	0.12	1.93	4.89	-0.05	2.22	5.10	-1.79	2.37	-0.70	0.97	3.63
Transition countries		Million $					Average annual growth (%)					
Albania	E. Europe	1.07	3.81	4.03	0.21	3.03	2.40	-1.28	0.63	-1.31	3.84	3.81
Bulgaria	E. Europe	2.87	3.91	1.35	-0.88	-3.75	-1.97	1.69	0.22	0.82	0.44	0.49
Czechoslovakia, for.	E. Europe	5.91	2.68	1.25	1.08	-3.00	-0.62	1.95	0.33	2.21	0.95	1.56
Hungary	E. Europe	6.29	2.71	2.81	-0.24	-1.45	-0.52	0.67	2.54	1.62	0.14	1.99
Poland	E. Europe	19.99	2.13	0.29	0.96	-1.10	0.32	-0.56	-0.67	2.17	1.12	0.06
Romania	E. Europe	9.56	3.36	3.96	-1.89	-0.60	-0.32	-0.53	1.63	-1.60	1.44	-0.20
Yugoslavia, former	E. Europe	9.21	2.64	2.48	-0.53	-0.68	1.03	1.68	1.87	0.63	1.22	2.09
Estonia	FSU, Baltic	0.55	3.32	1.98	-0.64	-6.89	2.31	1.40	0.19	-0.69	1.29	4.70
Latvia	FSU, Baltic	0.88	2.89	1.02	0.81	-9.20	3.19	1.51	-0.46	0.22	0.48	3.20
Lithuania	FSU, Baltic	1.87	4.08	0.45	1.94	-4.20	1.56	2.73	-0.83	1.35	0.68	0.95
Armenia	FSU, CAC	1.05	0.20	4.85	-1.47	-0.61	7.36	-4.27	2.10	0.59	1.67	5.14
Azerbaijan	FSU, CAC	2.27	4.40	6.93	-0.92	-2.98	4.64	1.58	2.80	-1.10	-0.71	3.02
Georgia	FSU, CAC	0.80	3.22	4.29	-1.59	-0.21	-5.29	-0.59	2.72	-0.64	0.57	-2.97
Kyrgyzstan	FSU, CAC	1.82	3.78	2.00	2.73	1.36	0.87	-0.76	-0.22	1.34	3.74	0.53
Tajikistan	FSU, CAC	1.30	4.52	3.90	0.92	-4.27	5.62	0.81	2.06	0.47	-0.96	2.86
Turkmenistan	FSU, CAC	2.95	4.00	3.78	4.01	2.21	4.72	-0.48	0.62	1.21	0.69	1.01
Uzbekistan	FSU, CAC	10.02	3.21	5.07	0.68	0.73	5.38	-0.50	2.18	-1.38	1.05	3.39
Belarus	FSU, E Euro.	7.13	2.92	1.11	1.45	-3.72	4.38	0.10	-0.28	0.99	0.19	4.74
Kazakhstan	FSU, E Euro	7.92	5.67	1.35	1.69	-7.22	4.21	3.83	-0.45	0.47	3.36	2.41
Moldova	FSU, E Euro	1.51	3.66	1.88	0.11	-6.63	-0.55	0.78	-0.04	0.32	0.52	2.71
Russian Federation	FSU, E Euro	50.61	3.08	0.41	1.40	-4.99	2.25	0.88	-1.35	0.85	1.42	4.29
Ukraine	FSU, E Euro	22.87	2.65	1.13	1.38	-6.04	2.91	0.41	-0.18	1.12	-0.07	5.35

Country	Region	Agricultural Output						Agricultural TFP				
		Avg 2006-09	1961-70	1971-80	1981-90	1991-00	2001-09	1961-70	1971-80	1981-90	1991-00	2001-09
Developed countries (DC)		Million $	Average annual growth (%)									
South Africa	Africa, DC	11.73	3.13	2.52	1.21	1.55	2.12	0.34	1.15	2.71	2.79	3.01
Japan	Asia, DC	18.45	2.99	1.40	0.51	-1.06	-0.36	2.42	2.17	1.11	1.51	2.43
Korea, Republic	Asia, DC	10.27	4.48	5.81	2.91	2.47	0.64	1.83	4.28	2.81	4.04	2.86
Singapore	Asia, DC	0.18	6.26	3.97	-0.32	-2.18	-0.12	6.71	7.37	13.15	1.00	-5.19
Taiwan (China)	Asia, DC	4.59	3.71	1.48	2.13	1.17	-1.88	2.51	0.73	1.68	3.03	0.51
Australia	Oceania, DC	23.45	2.95	1.84	1.67	3.55	-0.76	0.63	1.65	1.27	2.85	0.55
New Zealand	Oceania, DC	10.07	2.77	1.29	1.01	2.27	1.19	1.47	1.39	1.84	3.20	3.14
Canada	North America	28.00	2.80	2.28	1.25	2.48	1.96	1.41	-0.36	2.67	2.55	2.14
United States	North America	229.48	1.99	2.30	0.61	1.90	1.35	1.21	1.80	1.21	2.17	2.26
Austria	Europe, NW	4.62	1.22	1.18	-0.01	0.65	0.14	1.00	1.90	1.30	2.52	4.39
Belgium-Luxembourg	Europe, NW	6.32	2.08	0.36	1.66	1.67	-1.02	1.99	1.78	1.96	2.77	0.39
Denmark	Europe, NW	6.95	-0.25	1.77	1.20	0.99	0.56	-0.23	2.43	2.31	3.76	2.71
Finland	Europe, NW	2.26	0.95	0.81	-0.60	-0.27	0.41	0.05	2.62	1.50	-0.50	2.44
France	Europe, NW	41.28	1.51	1.17	0.43	0.74	-0.78	0.42	1.85	1.51	2.23	1.99
Germany	Europe, NW	35.34	1.87	0.92	0.25	0.19	0.47	2.12	1.05	2.05	2.21	2.98
Iceland	Europe, NW	0.10	-0.13	1.79	-2.12	0.80	1.77	-1.28	2.01	-0.98	2.20	1.75
Ireland	Europe, NW	4.59	1.95	3.19	1.51	0.80	-0.87	-0.22	2.38	1.44	0.93	1.17
Netherlands	Europe, NW	12.40	3.19	3.29	1.41	-0.35	0.84	2.32	1.59	1.49	1.37	2.41
Norway	Europe, NW	1.44	0.49	1.28	0.14	-0.20	0.30	0.92	0.91	1.18	0.56	2.37
Sweden	Europe, NW	3.10	-0.68	1.62	-1.00	0.53	-0.74	-0.31	2.20	1.56	1.82	0.84
Switzerland	Europe, NW	2.80	1.15	1.51	0.15	-0.79	0.52	0.43	1.06	0.06	1.74	2.02
United Kingdom	Europe, NW	17.83	1.45	1.53	0.55	-0.41	-0.06	1.97	1.30	0.58	0.18	1.00
Cyprus	Europe, South	0.38	7.21	-1.75	1.83	1.12	-2.99	5.24	1.61	2.95	2.00	-1.24
Greece	Europe, South	8.04	2.72	2.95	0.75	0.79	-2.29	3.13	4.04	1.72	1.36	-0.59
Italy	Europe, South	32.01	2.03	1.49	-0.26	0.32	-0.29	3.93	3.37	0.71	2.59	2.09
Portugal	Europe, South	4.17	0.23	-0.44	2.04	0.66	-0.24	1.19	-2.38	3.50	1.52	1.85

Output is gross agricultural output measuring in constant 2005 international dollars (FAO). TFP growth is the difference between the rate of growth in gross output and total input, where the growth in total input is aggregate growth in agricultural land, labor, livestock herds, farm machinery and fertilizer use (see text for further explanation).
DC = Developed countries; LDC = less developed countries; FSU = former Soviet Union; CAC = Central Asia and Transcaucasia. Regions are defined by the author.
The average annual growth rate in series Y is found by regressing the natural log of Y against time, i.e., the parameter B in ln(Y) = A + Bt.