Bio-based and Applied Economics 4(3): 201-234, 2015
DOI: 10.13128/BAE-17151

Full Research Article

Accounting for growth in global agriculture

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Date of submission: August 21st, 2015; accepted October 4th, 2015

Abstract. Rising prices of agricultural commodities have renewed concerns about constraints to agricultural productivity. To assess productivity trends, total factor productivity (TFP) is generally preferred to partial productivity indexes as an indicator of technical and efficiency changes because it is more closely related to the unit costs of production. But measuring TFP is demanding of data, and developing comprehensive and comparable indexes of international agricultural TFP has been challenging. This study proposes a growth accounting approach, using FAO data on quantity changes in inputs and outputs and aggregating input changes using cost shares derived from other sources, as a consistent way of constructing agricultural TFP indexes for world agriculture. This produces aggregate growth rates for agricultural output, input and TFP at the country, regional and global levels. Results suggest that the rate of agricultural TFP growth accelerated in recent decades, especially in developing countries. Most regions of the world now rely on productivity-based growth rather than resource-based growth to raise agricultural output.

Keywords. Growth accounting, technical change, total factor productivity

JEL Codes. Q16, O13

1. Introduction

The reversal of the long-run decline in global prices for agricultural commodities that occurred in the first decade of the 21st Century raised concern that the rate of productivity growth in world agriculture may have slowed. If so, this would pose serious challenges to meeting projected future growth in the global demand for food and exacerbate environmental degradation as more resources would be converted to produce food. In fact, there is evidence of a slowdown in the rate of growth in cereal grain yields (Alston *et al.*, 2009). However, single-factor productivity measures like crop yield mix the effects of technical change with intensified use of other inputs like fertilizer and irrigation. Since total factor productivity (TFP) accounts for the contributions of all inputs to production, it is a better indicator of technical or efficiency improvements and more closely associated with changes in production cost.

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ISSN 2280-6180 (print)
ISSN 2280-6172 (online)

TFP is the real output produced by a firm or industry over a period of time divided by the real input used by that firm or industry over the same period of time (where real input refers to the combined use of land, labor, capital and material resources employed in production). It is often difficult to provide meaningful definitions of real output or real input due to the heterogeneity of outputs produced and inputs used. However, it is possible to provide meaningful definitions of the *output growth* and *input growth* between any two periods of time using index number theory (Caves *et al.*, 1982). Using information on output and input quantities and prices alone from two or more points in time, one can derive indexes of output and input growth, with the difference in their growth being defined as the growth in TFP.

The measurement challenge for TFP growth is whether information is available to represent output and input quantities and prices at a sufficiently disaggregated level to account to quality differences in these measures. Most of the readily available data for measuring TFP growth is found in high-income countries, which is why most agricultural TFP studies have focused on these countries. From a series of studies compiled by Alston *et al.* (2010), it appears that the growth rate of agricultural TFP may have slowed in a number of developed countries (namely, Australia, the United Kingdom, South Africa and possibly the United States), lending further support to the productivity slowdown hypothesis.

For most countries, and for the world as a whole, estimates of agricultural TFP can only be approximated. While there are limitations with the coverage of output data, the larger challenge is with the input data. While the FAO provides quantity information on several of the major inputs used in agricultural production, data on their costs and prices is mostly lacking. Arnade (1994) used Data Envelope Analysis (DEA) to get around the lack of input price data, solving linear programming problems to trace out a world agricultural productivity frontier and determine the distance of each country to that frontier. In this framework, shifts in the frontier over time (defined over all or a group of countries) represents technical change, whereas the distance of a particular county to the frontier represents technical inefficiency of that country. Together, changes in technology and efficiency sum to the rate of growth in TFP. Coelli and Rao (2005) give a summary of studies that have used this approach and provide updated estimates comparing agricultural TFP among 93 countries over 1980-2000. However, the DEA method is sensitive to the "dimensionality" issue: as more or fewer countries or inputs are added to the analysis, results change. It is also sensitive to outliers. Further, as Coelli and Rao (2005) point out, the solutions to the linear programming problems provide shadow values for the inputs, which in many cases appear to be implausible, at least at the country level (implying, for example, that the marginal values of land, labor and/or other inputs are often zero).

Another approach to dealing with the lack of input prices (or actually, lack of input cost shares), was proposed by Avila and Evenson (2010). They used input cost shares estimated from agricultural censuses in Brazil and India to impute cost shares for other developing countries (specifically, they applied India cost shares to Asia and Africa and Brazilian cost shares to Latin America, making some adjustments based on relative input intensities per hectare). Applying these cost shares to input quantities from FAO, they estimates agricultural TFP growth rates for 78 developing countries for 1961-1980 and 1981-2000. Unlike many of the DEA models which found that agricultural TFP growth was apparently negative – even for countries experiencing the Green Revolution of the 1970s and 1980s – Avila and Evenson (2004) reported positive and accelerating TFP growth for these developing countries.

Nin-Pratt and Yu (2010) used the Avila and Evenson (2010) cost shares to set upper and lower bounds on the input shadow values in a DEA application (which they called "constrained" TFP) to generate agricultural TFP estimates for 63 developing countries over 1967-2006. They found significant differences between estimates of constrained and unconstrained TFP growth and their constrained TFP growth results were closer to those of Avila and Evenson (2010). Findings from these studies suggest the average rate of agricultural TFP growth for developing countries had risen since the 1980s but there remained large variation among countries. This first result, of higher average TFP growth in recent decades, seems at odds with the productivity slowdown hypothesis, but these estimates typically lag at least a decade from the present and rarely have complete global coverage.

The present study uses growth accounting to construct TFP indexes for agriculture world-wide. The approach is similar to what Avila and Evenson (2010) proposed, but with a much broader and representative set of input cost shares for constructing agricultural input indexes. The analysis includes industrialized, developing and transition countries for a near-complete global coverage. It extends my earlier work (Fuglie 2008, 2010b, 2012) which has steadily developed and improved upon this approach. In addition to providing updated evidence on agricultural TFP growth (extending the estimates through 2012), the principal methodological innovation in this paper is to include a comprehensive measure of animal feed in the aggregate input index. Most studies of international agricultural productivity have ignored animal feed as an input in agricultural production, using the FAO measure of net agricultural output (which subtracts from gross output the portion of crops kept on farms for use as feed) to net out animal feed. However, this measure does not account for by-products from food manufacturing and other industries that are processed into animal feed nor crops that are imported for use as feed. The present study extends the approach suggested by Nin *et al.* (2003) to construct a more complete estimate of animal feed using the FAO Commodity Balance Sheets. It is expected that the revised estimates of aggregate agricultural inputs will be higher (and thus agricultural TFP somewhat lower) as a result of this more complete accounting of inputs used in agriculture.

More complete coverage of inputs provides better estimates of TFP and improves our ability to track growth in productivity. But as the input quantities are generally not adjusted for quality, these estimates should be considered as "raw TFP" (Avila and Evenson, 2010). In particular, labor inputs are measured in terms of the number of economically active adults employed primarily in agriculture. Part-time employment and the improvement in schooling and skills are not factored in. Many of the national TFP studies from industrialized countries have gone to great lengths to account for the rising quality of labor and other inputs in measuring the change of total inputs used in agriculture (e.g., see Ball, 1985; Ball *et al.*, 1997). Controlling for changes in input quality will generally raise the estimate of input growth and therefore lower the residual between output and input growth. We should expect that the raw TFP growth estimates reported here should be somewhat higher than the TFP growth estimates from these national studies.

Another point regarding the interpretation of TFP growth is that since it is estimated as a residual between output and input growth, it will tend to reflect not just pure technical change but also economies of scale, improvements in technical and allocative efficiency, and changes in the quality of natural resources like soil, water and climate. The latter is especially important in light of the impact of climate change on agriculture. If climate change is negatively affecting agricultural productivity, say due to the effects of increased heat stress on crop yields, then estimates of TFP growth would indicate the net effect of the gains from technical, efficiency and scale improvements against the losses in productivity from natural resource degradation.

A final point to keep in mind is that simply measuring TFP growth does not tell us anything about the causes of this growth. However, in order to have an explanation for TFP growth, it is first necessary to have a good measure of it. The next section of the paper describes in detail the methods and sources of data used to construct agricultural TFP indexes for each country, region and the world as a whole. This is followed by a discussion of some of the main findings on trends in global agricultural productivity growth during 1961-2012. The final section concludes and offers some suggestions for future research.

2. Methods and Data

2.1 Measuring Total Factor Productivity Growth

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.

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:

$$TFP = Y/X \tag{1}$$

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 (1) over time can be written as:

$$\frac{d\ln(TFP)}{dt} = \frac{d\ln(Y)}{dt} - \frac{d\ln(X)}{dt} \tag{2}$$

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 (2) can be written as:

$$\ln\frac{TFP_t}{TFP_{t-1}} = \sum_i R_i \ln\frac{Y_{i,t}}{Y_{i,t-1}} - \sum_j S_j \ln\frac{X_{j,t}}{X_{j,t-1}} \tag{3}$$

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 output commodity weighted by its revenue share. Similarly, total input growth is found by summing the growth rate of each factor of production, 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 significant 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, cost shares are varied 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 (3) for measuring agricultural productivity change is a lack of representative cost share data for most countries. For the present study, direct estimates of cost shares were assembled for 22 countries representing about two-thirds of world agricultural output. For another set of countries where input prices are not available or market-determined, (Sub-Saharan Africa and transition economies of the former Soviet Union and Eastern Europe) econometric estimates of production elasticities were used in place of cost shares. For remaining countries, representing about 25% of world agricultural output, cost shares are approximated by applying cost shares from a "like" country. The section below on "input cost shares" provides details on the data sources and assumptions.

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

$$g\left(Y\right) = g\left(TFP\right) + \sum_{j=1}^{J} S_j g\left(X_j\right) \tag{4}$$

I call equation (4) a *cost decomposition* of output growth since each $S_j g(X_j)$ term gives the growth in cost from using more of the jth input to increase output.[1] It is also pos-

[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 capital inputs (land) so as to maintain the zero profit (total cost= total revenue) condition.

sible 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:

$$g\left(Y\right) = g\left(X_1\right) + g\left(\frac{Y}{X_1}\right) \tag{5}$$

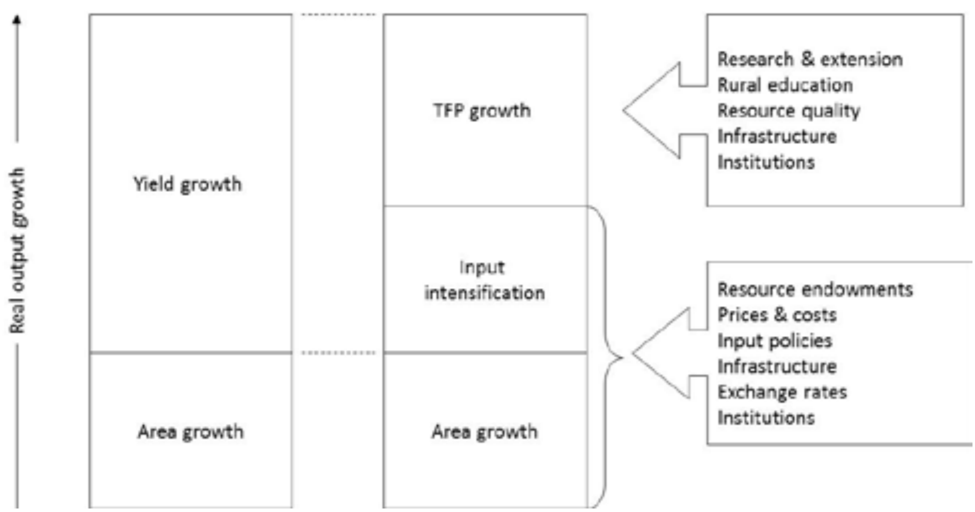
This decomposition corresponds to what is commonly referred to as *extensification* (land expansion) and *intensification* (land yield growth). We can further decompose yield growth into the share due to TFP and the share due to using other inputs more intensively per unit of land:

$$g\left(Y\right) = g\left(X_1\right) + g\left(TFP\right) + \sum_{j=2}^{J} S_j \; g\left(\frac{X_j}{X_1}\right) \tag{6}$$

I call equation (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.

Figure 1 gives a graphical depiction of the growth decomposition described in equation (6). The height of the bars indicate the growth rate of real output. Growth in real output is first decomposed into growth attributable to agricultural land expansion (extensification) and growth attributable to raising yield per hectare (intensification). Finally, yield growth itself is decomposed into input intensification (i.e., more capital, labour and fertilizer per hectare of land), and TFP growth, where TFP reflects the efficiency with which all inputs are transformed into outputs. Improvements in TFP are driven by technological change, improved technical and allocative efficiency in resource use, and scale economies. The decomposition of output growth into these components is both intuitively appealing and has some direct policy relevance: land expansion and input intensification

Figure 1. Growth in Output, Yield and TFP.



are strongly influenced by changes in resource endowments and relative prices. For example, increasing population density or higher crop prices can induce more intensive use of existing farmland and investments in land improvement (Boserup, 1965). But in the short run, the ability to raise yield through intensification is largely confined to existing technology. Changes in TFP, on the other hand, are driven by changes in technology and allocative efficiency. Yield growth resulting from incremental improvements to technology can be sustained over the long-run through investments in research and development (R&D).

2.2 Data

FAO's 1961-2012 annual time series of crop and livestock commodity outputs and land, labor, livestock, farm machinery, inorganic fertilizers and animal feed inputs are the primary source used to construct the national, regional and global quantity measures. In some cases these data are modified or supplemented with data from other sources (such as national statistical agencies) when they are considered to be more accurate or up-to-date, as described below.

Output

For agricultural output, FAO publishes estimates of annual production of 198 crop and livestock commodities by country since 1961. FAO also aggregates production into a measure of the gross agricultural output using a common set of global average 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 agricultural output. 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 agricultural output 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 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 $\lambda = 6.25$ as recommended for annual data by Ravn and Uhlig, 2002). 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 productivity trends and that annual variation around this trend is primarily due to short-term disturbances like weather.

Inputs

Inputs are divided into six categories: farm labor, agricultural land, two forms of capital inputs – farm machinery and livestock, and two types of intermediate inputs – inorganic fertilizers and animal feed. The primary source of information is FAO, which published annual estimates beginning in 1961 (and for farm labor beginning in 1980) for each country, except for former Soviet Socialist Republics (SSRs) for which data begin in 1992. I extend the time series for each of the SSRs back to 1980 from Shend (1993) and further to 1965 using Lerman *et al.* (2003).

Farm labor is the total number of adults (males and females) who are economically active in agriculture. FAO currently publishes farm labor estimates and projections for each country of the world from 1980 to 2020, although previously FAO also published estimates for 1961-1979. FAO estimates are used for each country except China, Nigeria and transition economies (former Soviet Union and Eastern Europe). Estimates are backcast from 1980 to 1961 using the agricultural labor force growth rates from the 2006 version of FAO labor force statistics, which included estimates from 1961 onward. For China, agricultural labor estimates are from the Statistical Yearbooks of the National Bureau of Statistics of China. For Nigeria, labor force estimates are from Fuglie and Rada (2013), who determined that FAO farm labor force estimates for this country were grossly undercounted. To derive more plausible estimates, Fuglie and Rada (2013) used FAO data (2006 version) for 1961-1966 and then extrapolated them to the present assuming a 2% annual growth rate. For transition economies, national agricultural statistical sources are used, as reported in EUROSTAT for the Baltic countries and Eastern Europe, CISSTAT for Russia, Belorussia and Moldova, the International Labor Organization's LABORSTA for Ukraine, and the Asian Development Bank for Asiatic former Soviet republics. Pre-1992 labor estimates for these countries are from Shend (1980) and Lerman *et al.* (2003).

Agricultural land is the area in permanent crops (perennials), annual crops, and permanent pasture. Cropland (permanent and annual crops) is further divided into rainfed area and area equipped for irrigation. The areas of rainfed cropland, irrigated area and permanent pasture are then aggregated 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). However, for agricultural cropland in Sub-Saharan Africa total area harvested for all crops is used rather than the FAO cropland series (Fuglie and Rada, 2013). For China I use sown crop area (National Bureau of Statistics of China) for cropland, given unreasonable discontinuities in the cropland series of both the FAO and Chinese government sources (Fan and Zhang, 2002). For New Zealand, FAO cropland series prior to 2002 fails to reflect changes in a consistent definition over time. For cropland, I use the area in grain, seed, fodder and horticultural crops from Statistics New Zealand (2003) for 1961-2001, and FAO data from 2002 onward. For similar reasons, for cropland in Indonesia prior to 1990 national estimates from the Badan Pusat Statistik as described in Fuglie (2010b) are used.

Farm machinery is the total metric horse-power (CV) of major farm equipment in use.[2] It is the aggregation of the number of 4-wheel riding tractors, 2-wheel pedestrian tractors, power harvester-threshers, and milking machines, expressed in "40-CV tractor-equivalents." The average CV per machine is assumed to be 40 CV per 4-wheel tractor, 12 CV per 2-wheel tractor, 20 CV per power harvester-thresher, and 1 CV per milking machine. However, due to insufficient information no adjustment is made for differences across countries or over time in farm machinery sizes within these categories, except for China, which reports farm machinery inventories in power units (National Statistical Bureau of China).

The FAO reports continuous time series data for 4-wheel tractors, harvest-threshers and milking machines, but not 2-wheel walking tractors. For many developing countries, particularly in Asia, 2-wheel tractors have been a major component of farm mechanization. For 2-wheel tractors, FAO reports numbers in use for 1970s but then discontinued this series until recommencing it in 2002. For interim years, I collected national farm machinery statistics on 2-wheel tractors in use from the agricultural censuses of China, Japan, South Korea, Taiwan, Thailand, Philippines, Indonesia, Indian, Bangladesh, Pakistan, and Sri Lanka, and interpolated between census years. These countries constitute most of the global use of 2-wheel tractors in use on farms.

Presently, FAO farm machinery statistics only extend to 2009 (and for many countries they may not extend past 2005).[3] To extend estimates of farm machinery to 2012, national statistics on the number of tractors and combine-harvested from more recent years were collected for a number of countries: Bangladesh (Hassan, 2013), China (National Statistical Bureau of China, 2014), Europe (Eurostat), India (Singh *et al.*, 2015), Japan (Ministry of Agriculture, Forestry and Fisheries), Russia (Russian Federation Federal State Statistics Service, 2015), and the United States (National Agricultural Statistical Service, 2014). For remaining missing data, farm machinery stocks were extrapolated using the average growth rate from the three most recent years of available data.

Livestock Capital is the aggregate value of animals used for breeding, milking, egg laying, wool production, and to provide animal traction. To approximate livestock capital, total inventories of animals on farms, measured in "cattle equivalents" are used.[4] Inven-

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[2] This measure of capital stock is based on physical inventories. An alternative is to estimate capital stock as the sum of accumulated past investments with depreciation (perpetual inventories). Larson *et al.* (2000) used the perpetual inventory method to estimate agricultural capital stocks for 62 countries over 1967-1992. This is a promising effort but coverage remains incomplete.

[3] In addition to the number of farm machines in use, FAO reports the value of gross capital stock of farm machinery and equipment annually from 1975 to 2007. This value is computed by multiplying the number of 4-wheel tractors, harvester-threshers, and milking machines in use by a fixed unit price and adding $35 of hand tools per agricultural worker. Thus, the two measures, of machines in use and the value of gross capital stock of farm machinery, are highly correlated. However, 2-wheel tractors are not included in the FAO estimate of gross capital stock.

[4] The FAO agricultural capital stock series makes a distinction between livestock "fixed assets" and livestock "inventories" simply by treating 85% of value of farm animals as fixed assets (breeding stock) and the rest as pure inventories. Since we are primarily interested in the growth rate of livestock capital, it makes no difference which measure is used since they are directly proportional to one another.

tories include dairy cows, other cattle, water buffalo, camels, horses, 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, dairy cows and horses, 1.00 for other 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. The source of the data is the International Fertilizer Association, except for small countries, which is from FAO.

Animal Feed is the total amount of crop (except fodder), animal and fish products used for feed, measured in tonnes of dry-matter (DM) equivalents. Data on commodities used for animal feed are from the FAO Commodity Balance Sheets. In addition to total DM, total metabolizable energy (ME)[5] and total crude protein (CP) of animal feeds were estimated.[6] Parameters for the DM, CP and ME Mcal/kg (for ruminants) for each type of feed are from the National Research Council (1982). See Appendix Table A1 for details.

Table 1 shows how the composition of global animal feed evolved over the three decades between 1976-1980 and 2006-2010 (reported in 5-year average annual quantities). There was a significant shift toward greater use of oilcrops and oilcrop meals (or cakes) in feed, contributing to an overall rise in the protein content of animal feeds. Over these three decades, the amount of CP in the global feed mix rose by 84%, while total DM and ME increased by 58 and 56%, respectively (DM and ME are highly correlated with each other). By 2006-2010, cereal grains (including processing by-products such as brans and distiller grains) contributed about 64% of total ME and 41% of total CP. The share of animal and fish products (whey, milk, meat and fish products) in global animal feeds declined over time.

While these six 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, veterinary pharmaceuticals, energy, and services from farm structures. However, more detailed input data are available from several of the national studies from which input cost shares are derived (see section below on Input Cost Shares). To account for these inputs, I assume that their growth rate is correlated with one of the six input variables just described and include their cost with the related input. For instance, 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 veterinary medicines are included in the animal feed cost share, and energy costs are included in the farm machinery cost share. So long as the growth rates of the observed input and its unobserved counterparts are similar, then the model captures the growth of the unobserved inputs in the aggregate input index.

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[5] Metabolizable energy is total energy of feed consumed after accounting for energy in feces, urine and gasses.

[6] For a few small countries the FAO commodity balance sheets do not report feed utilization data. For these countries, regional average amounts of DM, CP and ME per livestock unit are multiplied by the number of livestock units in that country to estimate total feed. All of these countries are estimated to use substantially less than one million tonnes of feed per year and the total feed use of these countries combined amounts to less than 0.005% of global feed use.

Table 1. The Changing Composition of Global Animal Feed (average annual quantities).

	Million metric tons (dry matter)		% change	Share of total	
	1976-80	2006-10		1976-80	2006-10
Quantity					
Cereals (grain & bran)	644	891	38.4	0.72	0.63
Oilseeds (crops, meal, oil)	93	278	199.0	0.10	0.20
Roots and tubers	49	58	19.0	0.05	0.04
Other crops	30	71	139.6	0.03	0.05
Milk, whey & butter	65	91	40.4	0.07	0.06
Meat & fish (meat, meal, oil)	15	19	23.5	0.02	0.01
TOTAL	896	1,409	57.3	1.00	1.00
Metabolizable Energy					
Cereals (grain & bran)	1,878	2,613	39.2	0.72	0.64
Oilseeds (crops, meal, oil)	259	794	206.6	0.10	0.20
Roots and tubers	137	162	18.1	0.05	0.04
Other crops	67	147	120.7	0.03	0.04
Milk, whey & butter	211	278	32.0	0.08	0.07
Meat & fish (meat, meal, oil)	50	63	26.5	0.02	0.02
TOTAL	2,601	4,058	56.0	1.00	1.00
Crude Protein					
Cereals (grain & bran)	73.9	100.1	35.4	0.55	0.41
Oilseeds (crops, meal, oil)	35.5	108.6	205.9	0.27	0.44
Roots and tubers	2.7	2.6	-3.8	0.02	0.01
Other crops	3.4	11.4	238.5	0.03	0.05
Milk, whey & butter	9.9	12.8	29.9	0.07	0.05
Meat & fish (meat, meal, oil)	8.0	9.7	21.4	0.06	0.04
TOTAL	133.4	245.3	83.9	1.00	1.00

Source: Feed quantities from FAO Commodity Balance Sheets; feed composition from National Research Council (1982).

2.3 Land Quality

The FAO agricultural database provides time-series estimates of agricultural land by country and categorizes this as either permanent pasture or cropland (which is further divided in arable and permanent crop land). 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 *et al.*, 1997).

In this study, because I estimate only productivity growth rather than productivity levels, differences in land quality across countries is less of an issue. 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 a hectare of irrigated land would likely make a considerably larger contribution to output growth than adding a hectare 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 bloc countries, Asia-Pacific, Latin America and the Caribbean, West Asia and North Africa, and Sub-Saharan Africa). I then regress the log of agricultural land yield in a country (its total output *Y* divided by the sum of cropland and pasture area) against the proportions of agricultural land in rain-fed cropland (*Rainfed*), irrigated cropland (*Irrig*), and permanent pasture (*Pasture*). Multiplying the land-use proportions by the regional indicator variables allows the coefficients to vary among regions:

$$ln\ \frac{Y}{Cropland + Pasture} = \sum_{i=1}^{5}\alpha_i\left(Rainfed * Region_i\right)$$

$$+\sum_i \beta_i\left(Pasture * Region_i\right) + \sum_i \gamma_i\left(Irrig * Region_i\right) \qquad (7)$$

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 (7) reflect these differences and provide a ready means of weighting the relative qualities of these land classes.

The regression estimates show that, on average, one hectare of irrigated land was between 1.1 to 3.0 times as productive as rainfed cropland, which in turn was 10-20 times as productive as permanent pasture. 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 2. When summed up using unadjusted data, between 1961 and 2012 total global agricultural land expanded from 4,429 million ha (mHa) to 4,930 mHa, or by about 11%. When adjusted for quality, “effective” agricultural land expanded by 28%, or nearly 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.

Table 2. Global Agricultural Land Use Changes Between 1961 and 2012 (millions of hectares).

		Developed Countries	Transition countries	Developing countries	World
		(millions of hectares)			
Rainfed Cropland	1961	357	272	567	1,196
	2012	309	219	734	1,262
	% change	-14%	-19%	30%	6%
Irrigated Cropland	1961	33	11	100	145
	2012	50	23	242	315
	% change	51%	110%	141%	118%
Permanent Pasture	1961	885	358	1,845	3,089
	2012	774	380	2,199	3,353
	% change	-13%	6%	19%	9%
Total Agricultural Land	1961	1,276	641	2,512	4,429
	2012	1,133	622	3,175	4,930
	% change	-11%	-3%	26%	11%
		(millions of hectares of rainfed cropland-equivalents)			
Quality-adjusted Agricultural Land	1961	505	329	884	1,718
	2012	482	305	1,419	2,206
	% change	-4%	-7%	60%	28%

Source: Agricultural land area from FAO, with adjustments made for China, Indonesia and New Zealand based on national data sources. 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 regression analysis (see text).

This adjustment for changes in different classes of land allows us to further refine the resource decomposition of output growth in equation (6) to isolate the contribution of irrigation apart from expansion in agricultural area to output growth. Letting X_1 be the quality-adjusted quantity of land (and for simplicity, dropping the *Region* subscripts on the land quality parameters), then a change in X_1 is given by

$$\Delta X_1 = \alpha\Delta(Cropland) + \beta\Delta(Pasture) + (\gamma\text{-}\alpha)\Delta(Irrig). \quad (8)$$

The first two right-hand-side 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 isolates the contribution of irrigation expansion: (γ-α)*100% gives the percent augmentation to yield, holding other factors fixed, from equipping a hectare of cropland with supplemental irrigation. Dividing equation (8) 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 (6), the resource decomposition expression shows the contributions to agricultural growth from expansion of agricultural land, extension of irrigation, intensification of other inputs per hectare, and improvements in TFP:

$$g\left(Y\right)= \theta_c \alpha g\left(X_{1c}\right)+\theta_p \beta g\left(X_{1p}\right)+\theta_w\left(\gamma-\alpha\right)g\left(X_{1w}\right) + \sum_{J=2}^{J} S_j g\,\frac{X_j}{X_1} + g\left(TFP\right) \tag{9}$$

where θ_c, θ_p and θ_w are the shares of quality-adjusted agricultural land in crops (X_{1c}), pasture (X_{1p}), and irrigated area (X_{1w}), respectively (note: $X_1 = X_{1c} + X_{1p} + X_{1w}$). The first two terms [$\theta_c \alpha g(X_{1c}) + \theta_p \beta g(X_{1p})$] give the share of output growth attributable to land expansion (holding yield fixed), while the third term [$\theta_w(\gamma$-$\alpha)g(X_{1w})$] indicates the share of output growth due to the extension of irrigation (holding other inputs fixed). The fourth term of equation (9) gives the contribution to growth of input intensification and the last term the contribution of growth in total factor productivity.

Input Cost Shares

The FAO (and supplementary) quantity data allow us to calculate the growth rates for six categories of production inputs (land, labor, machinery capital, livestock capital, and material inputs represented by fertilizer and feed), but to combine these into an aggregate input measure requires information on their cost shares or production elasticities. For this I draw upon 19 studies that have estimated nationally or regionally representative cost shares or production elasticities for agricultural inputs (see Appendix Table A2 for a list of these studies and the cost shares derived from them). These costs shares are assumed to be representative of not only those nations but also for other countries in the same region. For instance, the cost shares from India were applied to other countries in South Asia, the cost shares for Indonesia were applied to other countries in Southeast Asia and the Pacific, the cost shares for Mexico were assigned to other countries in Central America and the Caribbean, and the cost shares for Brazil were applied to other countries in South America as well as the North Africa-West Asia region. 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. For agricultural capital, some of these studies only reported an aggregate cost share for all capital services. To partition capital services into machinery and livestock capital services, I used the average proportions of capital stock in machinery, livestock and tree capital for low, middle and high income countries reported in Butzer *et al.* (2012), and assigned the cost share of capital services from trees to land.

While the lack of direct observations on input cost shares for most countries introduces uncertainty in the TFP estimation, the countries for which cost shares are observed represent about 65% of the global agricultural economy. This proportion rises to three-fourths when Sub-Saharan Africa and the former Soviet Union are included – regions where econometrically-estimated production elasticities are used in place of cost shares.

Thus, countries to which input cost shares were imputed represent only one-quarter of world agricultural output. Another argument in support of this approach is that there is a significant degree of congruence among the cost shares reported for these country studies. For the developing countries for which cost shares data are available (India, Indonesia, China, Brazil and Mexico), farm-supplied inputs (land, labor, and livestock capital) account for between 60 and 90% of total costs, while inputs supplied by industry (machinery, or fixed capital, and purchased materials such as fertilizers and processed animal feed), 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. These patterns of input use is reflected in cost shares estimated or imputed for these countries.

Of perhaps greater concern is that some of the cost shares are becoming out of date. While the model attempts to adjust cost shares for each decade, it is still dependent on the information available from other published studies. If cost shares are unavailable for recent years, the model uses the last available data. In the case of China, the last nationally comprehensive input cost shares for which we have estimates is for 1992. In China's rapidly changing agricultural sector, we should expect that the use of costs modern industrialize inputs (and their share of total cost) to continue to rise, and TFP may be overestimated if the input index is not capturing the full extent of this transformation. Continued effort to extend and update national estimates of agricultural costs of production is necessary to undertake global productivity assessments like the one described here.

Country and Regional Productivity

Using the methodology and data described above agricultural TFP indexes are estimated for nearly every country of the world on an annual basis beginning in 1961 (and since 1965 for the independent states of the former Soviet Union). However, some countries have dissolved or are too small to have complete data. For the purpose of estimating long-run productivity trends, some national data are aggregated to create consistent political units over time. For example, data from the nations that formerly constituted Yugoslavia are added together to make comparisons with productivity before Yugoslavia's dissolution. Similarly, data were aggregated for Czechoslovakia, Ethiopia and the former Soviet Union (TFP series for individual SSR's begin in 1965). Because some small island nations have incomplete or zero values for some agricultural data, three composite territories were constructed by adding up available data for island states in the Lesser Antilles, Micronesia, and Polynesia. Altogether, 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, data are aggregated and TFP indexes estimated 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). Regional cost shares are the weighted averages of the national cost shares for the countries in a region. Appendix Table A3 provides a complete list of countries included in the analysis and the regional groupings.

3. Results: Growth in Agricultural Productivity

3.1 Sources of growth in global agriculture

Table 3 provides summary findings on productivity measures for the global agricultural economy as a whole over the past five decades and for the entire 1961-2012 period. The first two columns of results show average annual growth rates of total agricultural outputs and inputs and the remaining columns indicate growth rates in four measures of productivity: changes in TFP, labor productivity, land productivity, and cereal grain yield per hectare harvested. The average growth rate of world agricultural output remained remarkably stable over time, rising by 2.8% per year in the 1960s and between 2.1% and 2.5% per year in every subsequent decade. The source of output growth, however, shifted from being primarily input-driven to productivity-driven. Annual growth in total inputs fell from 2.8% in the 1960s, to between 1.5% and 1.7% in the 1970s and 1980s, and to less than 0.8% since 1991.

Table 3. Productivity Indicators for World Agriculture (average annual growth rate in percent).

Period	Gross output	Total input	Total factor productivity	Output per worker	Output per hectare of land	Cereal yield per area harvested
1961-1970	2.79	2.79	0.00	1.13	2.44	2.88
1971-1980	2.29	1.74	0.56	1.55	2.12	2.08
1981-1990	2.10	1.49	0.62	0.59	1.76	1.88
1991-2000	2.17	0.63	1.54	1.92	2.06	1.56
2001-2012	2.52	0.84	1.68	2.83	2.59	1.53
1961-2012	2.23	1.30	0.93	1.25	2.01	1.94

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 $\ln(Y) = A + Bt$.

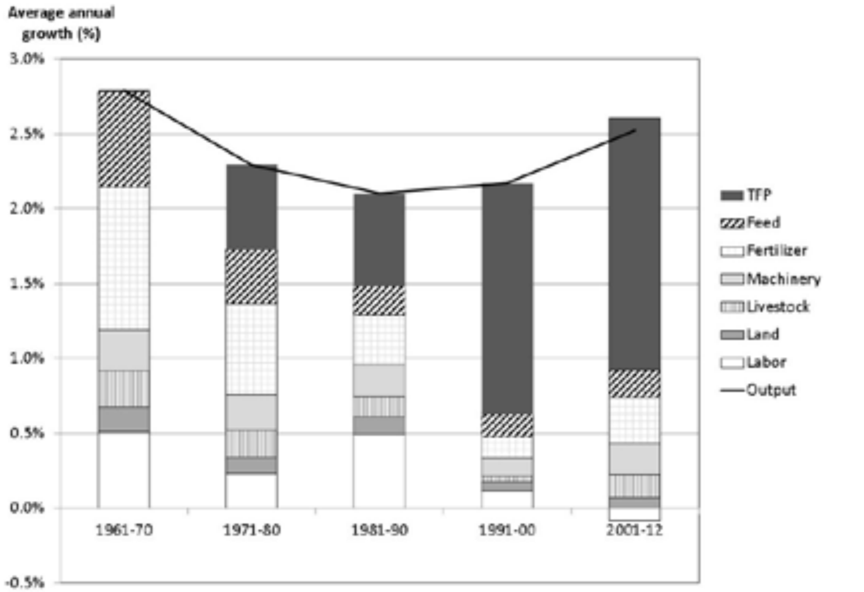
Offsetting the declining growth in inputs to keep output growth from falling has been productivity. Annual TFP growth rose from a global average of 0% in the 1960s to about 1.7% since 2001. The growth in global agricultural TFP has been generally lower than growth in either land or labor productivity. This reflects an intensification of capital and material inputs in agriculture, which raise land and labor productivity but may not affect TFP. Also, since the number of workers in agriculture expanded faster than agricultural land area, the growth rate in labor productivity tended to be lower than growth in land productivity. However, at the global level the agricultural labor force is now declining in absolute terms (while agricultural land is still expanding), so the rate of labor productivity growth now exceeds the rate of land productivity growth. In the most recent period of 2001-12, output per worker grew by 2.8% per year while output per hectare grew by 2.6% per year.

The growth rate in cereal yield per area harvested, which has been used as a harbinger of slowing productivity growth, has actually remained fairly stable since 1990, averaging at least 1.5% in annual decadal growth rates. This is below the nearly 2.9% rate of yield growth achieved in the 1960s, but does not appear to indicate a persistent slowdown in yield growth. Note that land productivity (output per hectare of land in agriculture) has generally grown more rapidly that crop yield per area harvested. The main reason for this in increased land use intensity. While yield of individual crops is generally calculated on the basis of area harvested, land productivity is based on total output in a calendar year from the area designated as agricultural land. Increased land use intensity has come about from greater use of multiple cropping and less cropland in fallow or devoted to fodder crops. Globally, cropland intensity (total area harvested divided by total area designated as cropland) gradually increased from about 0.74 in the 1960s to 0.78 in the 1990s, but then grew more rapidly reaching 0.85 by 2012.

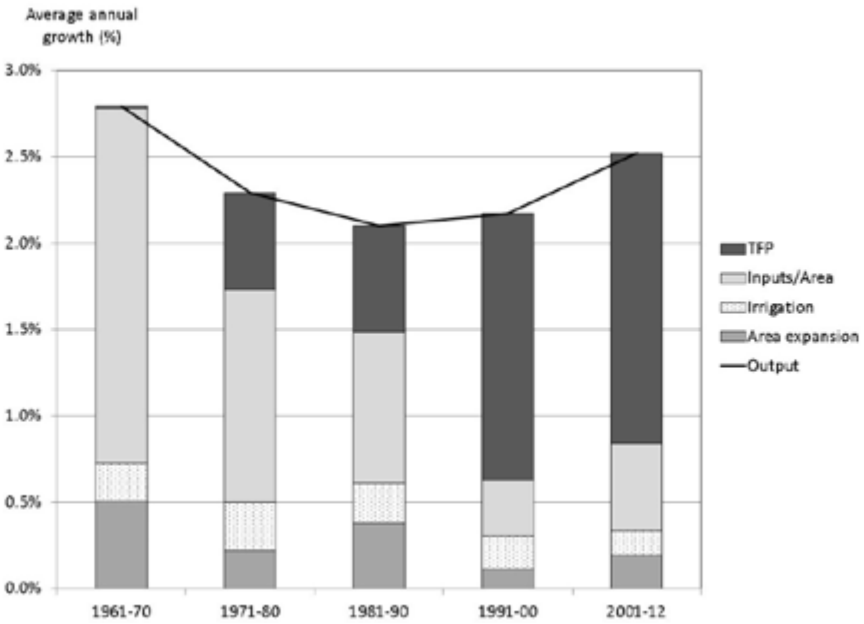
The decomposition of global output growth into contributions from inputs and TFP is depicted in Figure 2. The height of each column gives the average annual rate of output growth by decade. Over the entire 50-year period, total inputs grew at about 60% the rate of output growth, implying that improvement in TFP accounted for about 40% of new output. However, the rate of input growth declined over time, and TFP's contribution to output growth increased. By the 2001-12 period, TFP accounted for two-thirds of the growth in global agricultural production.

Figure 2, Panel A shows the contributions of various inputs to global agricultural growth according to their share of total costs (see equation 4), and the residual, or TFP. Increased use of material inputs, especially fertilizer, was a leading source of agricultural growth in the 1960s and 1970s, when green revolution cereal crop varieties became widely available in developing countries (these crop varieties were more responsive to fertilizers, especially when grown under irrigation). Fertilizer and animal feed 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 when these countries underwent a transition from a centrally planned to market economies. By the early 2000s agricultural resources in this region had stabilized, and there was a recovery in the global rate of input growth compared with the 1990s. Also in the 2000s, the world's agricultural labor force began to shrink for the first time in modern history. While the size of the agricultural labor had been falling for decades in industrialized countries, this is now also the case in China and Latin America. South Asia may also soon enter into a period where the absolute size of its farm labor force declines, if it hasn't already (Rada, 2013). In low income countries (especially those in Sub-Saharan Africa), the number of persons primarily employed in agriculture continues to rise although the share of the labor force working in agriculture is falling.

Figure 2. Sources of Global Agricultural Growth.



Panel A: Input Cost Decomposition



Panel B: Resource Decomposition.

The line shows the average annual growth rate in gross agricultural output during the period specified. The shaded components of the bar show the contribution of an input or productivity to total output growth. In Panel A, the growth rate of an input is weighted by its cost share. Panel B shows the growth rate in agricultural land (and the contribution of irrigation to raising effective land area) and the growth rate in yield, which is further decomposed into growth due to input intensification (inputs per area) and total factor productivity (TFP).

Figure 2 Panel B shows the *resource decomposition* of global agricultural growth slightly differently. Instead of by input cost as in Panel A, it shows the relative contribution of growth in land and water (irrigation), input intensification and TFP to growth (see equation 9). The rate of expansion in natural resources (land and water for irrigation) has diminished over time while the rate of growth in resource yield has risen. The underlying source of resource yield gain has shifted markedly from input intensification to improvement in TFP.

As expected, the inclusion of animal feed as an explicit input in production raised the growth rate of inputs and reduced the growth rate of TFP. However, the changes were not substantial and did not affect the general pattern of TFP growth acceleration world-wide over the study period. Over the entire 1961-2012, TFP growth without animal feed data (where feed use was assumed to grow at the same rate as the size of the livestock herd) averaged 1.01% per year, compared with 0.94% per year with animal feed inputs measured directly. The most significant effect of including animal feed was on TFP growth rates estimated for the former Soviet Union (FSU), especially the pre-transition era (1961-1991). Without including animal feed inputs, agricultural TFP in FSU remained virtually unchanged between 1961 and 1991, but with animal feed inputs it regressed by 23%. It would imply that during the Soviet era, agricultural growth was largely achieved by increasing levels of inputs but with declining marginal (and average) productivities in the use of those inputs.

3.2 Sources of agricultural growth by world region

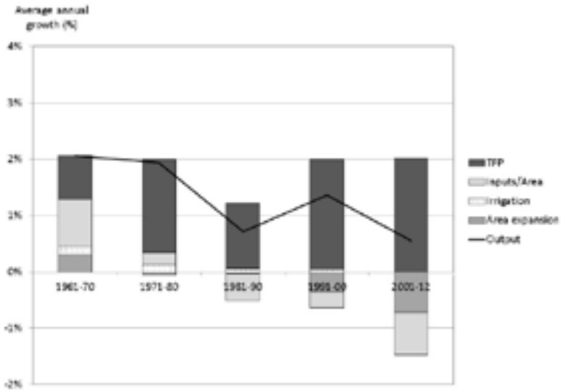
The same kind of growth analysis shown above for global agriculture can be carried out at the regional or country level. Figure 3 shows the contribution to agricultural growth from land, labor, capital, material inputs, and TFP for industrialized market economies, developing countries, and transition economies of the former Soviet Union and Eastern Europe. In industrialized economies (Panel A), the average annual rate of output growth fell from around 2% in the 1960s and 1970s to less than 1% in the last three decades. This slowdown in agricultural growth partly reflects Engel's Law, where per capita food demand is satiated and the growth in food demand reflects the growth in population, which is declining in these countries. Labor and land (and in recent decades, capital and materials as well) are being withdrawn from the agricultural sector. The fact that output is able to continue to expand in the face of these resource withdrawals is entirely due to TFP. The increase in the productivity of the resources remaining in the sector has been rapid enough to offset the decline in the amount of resources used. The high rate of TFP growth enabled the agricultural sectors of these countries to remain internationally competitive, and developed countries as a whole were net exporters of food.

Figure 3, Panel B indicates that improved productivity performance in developing countries was the proximate cause of the acceleration in global agricultural TFP growth after 1990. During the 1960s and 1970s, annual TFP growth averaged less than 1% for these countries, but since 1990 their agricultural TFP growth doubled to nearly 2% per year. For developing countries as a group, agricultural labor declined in absolute numbers over the 2001-12 period. This was primarily due to the exit of nearly 100 million Chinese farm workers to the non-farm sector. This trend is likely to accelerate in the coming decade not only in China but in other developing countries as well, as structural transformation moves workers out of agriculture. Sub-Saharan Africa, however, is expected to continue to experience growth in the size of its agricultural labor force at least through 2020, according to FAO projections.

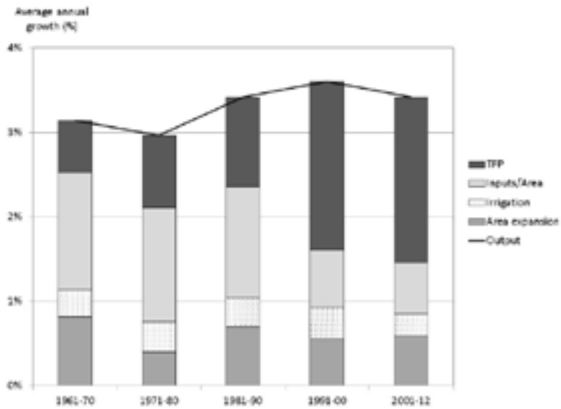
During the era of central planning (pre-1991), today's transition economies (Figure 3 Panel C) experienced agricultural TFP regression. All agricultural growth achieved in this region during this period was due to resource expansion, especially the rapid growth in material inputs like fertilizers and feed. Inputs supplied to agricultural were often at highly subsidized rates. When the Soviet bloc broke apart in 1991 and these countries began to move toward market economies, agriculture underwent a sharp contraction as subsidies were withdrawn from the sector. Agricultural output growth resumed in the 2000s, and most of this renewed growth can be attributed to improvement in TFP. More region-specific information on agricultural output TFP growth is provided in Table 4. These estimates show considerable heterogeneity in agricultural TFP growth rates among regions, which is even more pronounced if TFP is compared at the national level – not shown but available from Economic Research Service (2015). The outstanding productivity performers over the past few decades have been Brazil and China. Both are large agricultural producers (China has by far the largest agricultural sector in the world, accounting for 24% of gross agricultural output in 2013 according to FAO, and Brazil was the fourth largest, after India and the United States). TFP growth over the past several decades enabled China to remain largely self-sufficient in foodstuffs during a period of rapidly rising domestic food demand (due to population and per capita income growth) despite virtually no new land for agriculture. For Brazil, rapid TFP growth since the 1980s enabled it to move from a food deficit country to become a major exporter of agricultural commodities. Besides these countries, Southeast Asia, South Asia, and North Africa have also accelerated their agricultural TFP growth, achieving an average annual growth rate of over 2% since 2001.

A number of industrialized regions (Southern Europe, South Africa, Northeast Asia, and North America) have maintained agricultural TFP growth rates averaging at least 1.9% per year since 2001. These estimates are generally higher than those reported by country studies of agricultural TFP growth in these regions (Ball *et al.*, 2010). But recall that the TFP estimates reported in national studies typically make adjustments for quality changes in inputs, particularly labor, while the estimates reported in Table 4 do not. Adjusting an input for quality changes usually increases the share of output growth that is "accounted for" by growth in that input (e.g., adding one more skilled worker to the agricultural labor force raises output by more than adding one more unskilled worker). So, the TFP estimates in Table 4 should be interpreted as including not only the effects of technical change, but also the effects of using inputs of higher quality.

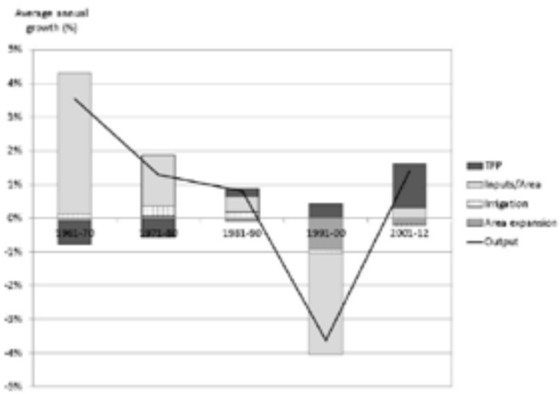
Figure 3. Sources of Agricultural Growth in Industrialized, Developing, and Transition Economies.



Panel A: Industrialized Countries.



Panel B: Developing Countries.



Panel C: Transition Economies.

Table 4. Agricultural Output and Total Factor Productivity Growth in Global Regions.

Region	1961-1970		1971-1980		1981-1990		1991-2000		2001-2012	
	Output	TFP	Output	TFP	Output	TFP	Output	TFP	Output	TFP
Developing Countries	3.15	0.61	2.97	0.85	3.42	1.06	3.61	2.00	3.42	1.96
Sub-Saharan Africa	3.01	0.17	1.07	-0.12	3.17	0.90	3.21	1.11	3.25	0.60
Latin America and Caribbean	3.05	0.80	3.32	1.33	2.27	0.90	3.15	2.02	3.19	2.00
Caribbean	1.70	-0.93	1.98	0.35	0.62	-0.52	-0.51	-0.26	0.39	-0.09
Central America	4.64	3.00	3.72	1.82	1.36	-1.79	2.96	2.68	2.21	1.90
Andean	2.97	1.44	2.82	1.08	2.79	0.47	3.20	1.78	2.66	1.46
Northeast (Brazil, mainly)	3.56	0.24	3.86	1.07	3.45	2.95	3.58	2.38	4.10	3.23
Southern Cone	1.80	0.49	2.87	2.57	1.13	-0.88	3.17	1.26	2.76	0.79
Asia (except West Asia)	3.28	0.74	3.11	1.02	3.64	1.41	3.71	2.55	3.49	2.61
Northeast Asia (China, mainly)	4.79	0.93	3.32	0.69	4.45	1.79	5.04	3.94	3.52	3.09
Southeast Asia	2.63	0.48	3.92	1.85	3.34	0.42	2.96	1.36	4.00	2.53
Pacific	2.52	-0.04	2.34	0.21	1.58	-0.65	2.06	0.51	2.16	0.92
South Asia	2.02	0.57	2.66	0.81	3.32	1.21	2.66	1.03	3.63	2.04
West Asia-North Africa	2.87	1.33	3.02	1.52	3.56	1.35	2.79	1.47	2.49	2.13
North Africa	2.62	1.28	1.57	0.34	4.19	2.52	3.26	1.58	3.49	2.70
West Asia	2.98	1.13	3.65	2.09	3.30	0.75	2.60	1.50	2.01	1.86
Industrialized Countries	2.06	0.76	1.94	1.62	0.72	1.14	1.36	1.94	0.56	2.00
Europe, Northern	1.55	0.93	1.36	1.26	0.51	1.40	0.37	1.38	0.11	1.44
Europe, Southern	2.11	1.43	1.96	1.87	0.69	1.13	1.32	1.88	-0.40	1.92
Japan-S. Korea-Taiwan	3.52	1.67	2.45	1.95	1.19	1.34	0.06	2.06	-0.28	2.02
Australia-New Zealand	2.90	0.91	1.69	1.59	1.49	1.18	3.22	2.79	0.67	1.35
Canada-USA	2.06	0.47	2.29	1.55	0.68	1.00	1.96	1.95	1.10	1.96
South Africa	3.18	-1.12	2.55	0.95	1.21	2.97	1.54	3.01	2.55	2.62
Transition countries	3.54	-0.69	1.29	-0.56	0.80	0.25	-3.61	0.41	1.39	1.30
Eastern Europe	2.67	-0.16	1.73	0.32	-0.03	0.60	-1.33	0.04	-1.18	0.08
Russia-Ukraine-Belarus-Moldova-Kazakhstan			0.76	-1.33	1.41	0.44	-5.43	1.00	2.35	2.39
Central Asia & Caucasus			4.71	1.93	0.55	-1.20	0.11	1.60	3.98	2.02
Baltic countries			0.93	-0.97	1.09	0.49	-6.00	-1.75	1.87	1.90
World	2.79	0.00	2.29	0.56	2.10	0.62	2.17	1.54	2.52	1.68

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 $\ln(Y) = A + Bt$.

Regions experiencing persistent low growth in agricultural TFP include Sub-Saharan Africa, Eastern Europe transition economies, Southern Cone countries of South America, the Caribbean and Pacific island nations. All of these regions show a growth trend in agricultural TFP of substantially less than 1%. Sub-Saharan Africa is the most critical case, given its large population, rapid population growth, and heavy dependence on agriculture as a source of livelihood. The fact that agricultural TFP growth has remained low for this region means that it has remained poor and food insecure, and increasingly dependent on food imports.

4. Conclusions

The principal advantage of a TFP measure of productivity growth is that it clearly distinguishes between resource expansion, resource substitution, and technical or efficiency improvements in resource utilization as sources of economic growth. Growth in TFP is more likely to be associated with lower unit costs of production, and, in long-run equilibrium, changes in market prices of output, than partial productivity indexes. The limitation of TFP is that it is subject to error if outputs and/or inputs are not fully or appropriately measured or if procedures for aggregation are biased.

This paper seeks to move toward plausible indexes of international agricultural TFP by constructing a more complete accounting of the inputs employed in the sector. Specifically, the paper develops an explicit measure for animal feed inputs, something which most previous studies of international agricultural productivity have ignored. Animal feed inputs are composed of much more than the portion of crops retained on farms and fed to animals. It includes many by-products of food manufacturing, such as oilseed cakes, distiller grains, milling brans, sugar and molasses, whey, animal slaughter waste, and fish meal. The paper proposes three ways of aggregating these diverse feed sources into a single quantity measure of feed input: dry-matter weight, metabolizable energy in Mcal, and tonnes of crude protein. It turns out that the growth in dry-matter weight and metabolizable energy are highly correlated, while the growth of crude protein has been more rapid, implying quality improvement in the overall animal feed mix over time. One direction for future work could be to develop a quality-adjusted measure of feed input that combines energy and protein (and perhaps other nutrients).

As expected, inclusion of animal feed in the measure of total agricultural inputs led to higher growth in measured agricultural inputs and thus lower growth in agricultural TFP for the world economy over 1961-2012, although the differences were not substantial. Results did not alter the central finding from my previous analyses using this approach (Fuglie, 2008, 2010b, 2012) that there has apparently been a significant acceleration in global agricultural productivity growth since the 1990s. This is in contrast to evidence – based primarily on partial productivity indexes like crop yield – that since around 1990 the rate of agricultural productivity has significantly slowed in most of the world (Alston *et al.*, 2009; Alston and Pardey, 2014). The evidence for accelerated productivity arises from the fact that the real growth of agricultural output has not fallen while growth rates for most agricultural inputs have declined. It suggests that much of the rapid growth in crop yield and land and labor productivity observed in the 1960s and 1970s was due to factor substitution (especially fertilizer for land and capital for labor), and once the growth of other factors is taken into account, the real gains in efficiency during these decades were not exceptional.

The present analysis suggests, though, that the global trend is hardly uniform. At least three general patterns of agricultural growth are evident:

1. In industrialized market economies, the agricultural output growth rate is slowing while input growth has turned negative. TFP growth offset the decline in resources to keep output from falling in absolute terms.

2. The dissolution of the Soviet Union in 1991 imparted a major shock to agriculture in transition economies as they began the adjustment from centrally-planned to market-oriented economies. In the 1990s, agricultural resources sharply contracted and output fell. Agricultural inputs stabilized in the early 2000s and agricultural growth resumed in former Soviet states but not yet in Eastern European. Agricultural TFP growth, which was negative during the Soviet era, turned positive following economic reforms.
3. In developing countries, agricultural productivity growth doubled from around 1% per year during 1960-1990 to around 2% per year during 1991-2012. Two large developing countries in particular, China and Brazil, have sustained exceptionally high TFP growth in recent decades. Several other developing regions, including Southeast Asia, Central America, and North Africa, also registered accelerated TFP growth in the 1990s and/or 2000s. Very recently, agricultural TFP growth in India has also accelerated. The major exception is the developing countries of Sub-Saharan Africa, where long-run TFP growth has remained below 1% per year.

Despite these generally optimistic findings on agricultural productivity growth, the next several decades present major challenges to maintaining present rates of improvement. The prospects for a general slowdown, even though it may not have yet occurred, are probably inevitable. One source of a slowdown, as Alston and Pardey (2014) argue, is if global investments in agricultural R&D are not sufficiently robust to create new productivity-enhancing technologies and offset technological obsolescence. Stagnant or declining spending on public agricultural R&D in industrialized countries, which has been a key source of major scientific advances for world agriculture, may put future productivity growth in agriculture at risk. Another source of a slowdown is likely to emerge from natural resource degradation, particularly from the warming of the climate. The effects on agriculture from climate change may be positive in some areas in the short term, but are likely to turn increasingly negative over time. Having a robust measure of agricultural TFP growth as outlined in this paper provides a promising means of tracking these developments and for analysing their causes and consequences.

Nonetheless, the measurement of world agricultural TFP continues to suffers from some serious limitations, so caution is warranted in its interpretation. Information on farm investments in new capital is incomplete, leading to deficiencies in the measurement of agricultural capital stock and capital services. Heterogeneous quality of inputs, especially land, may introduce serious measurement errors when aggregating across national and regional frontiers. The labor input, which is always hard to measure in agriculture where much of the work is done by unpaid family members, could be mismeasured if hours worked per capita changes, not to mention skill levels.

A broader issue in agricultural productivity measurement is the consumption of unpaid (but socially valuable) environmental resources. Agriculture imposes significant costs on the environment in the form of greenhouse gas emissions, soil and water quality degradation, consumption of scarce and non-renewable water resources, and loss of biodiversity. How agricultural productivity growth affects these costs is not well understood (although evidence being assembled by the OECD (2014) suggests that in many cases agricultural productivity growth is conserving of environmental as well as market resources). Insufficient understanding of the environmental inputs and outputs associated with agricultural production (and how to value them) represents a serious limitation to using any standard productivity index to judge questions of long-term sustainability of agricultural systems.

The important question about the usefulness of TFP is not so much whether it is complete as a productivity index, but rather does it convey more meaningful information than commonly used alternatives like crop yield? The same informational deficiencies that plague TFP also affect the interpretation of other available measures as indicators of the rate of technical change. The growth accounting approach proposed in this paper seems to provide additional and useful insights on the nature and sources of economic growth that partial productivity indexes lack. Efforts to construct TFP also point the way to what needs to be done to strengthen them.

Acknowledgements

The author would like to thank Ornella Maietta, Nicholas Rada and Davide Viaggi for their comments on an earlier draft of this paper. Nicholas Rada also contributes to building the ERS database on international agricultural productivity. The views expressed in this paper are the author's own and should not be attributed to the U.S. Department of Agriculture or the Economic Research Service.

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Appendix

Table A1. Composition and Price of Animal Feedstuffs.

Feed type	Price (2005 $/T)	Dry matter (%)	Crude protein (%)	Dietary energy (Mcal/kg)
Wheat	158	89	14.2	3.45
Rice (milled equivalent)	279	89	7.6	3.47
Barley	119	88	11.9	3.27
Maize	142	89	9.6	3.40
Rye	112	88	12.1	3.24
Oats	114	89	11.8	3.02
Millet	181	90	11.6	3.34
Sorghum	154	90	11.1	3.40
Cereals, other	142	89	9.6	3.40
Brans	158	89	15.2	2.74
Potatoes	30	23	2.2	0.84
Cassava	30	37	1.5	1.31
Yams	30	23	2.2	0.84
Sweet potatoes	30	37	1.5	1.31
Roots & tubers, other	30	37	1.5	1.31
Sugar cane	33	15	1.2	0.41
Sugar beet	43	11	1.5	0.38
Molasses	440	94	9.7	2.91
Sugar (raw equivalent)	440	100	0.0	4.30
Pulses (beans, peas)	556	89	22.6	3.31
Oilcrops	274	90	39.2	3.67
Vegetable oils	274	100	0.0	8.85
Soybean meal	274	90	42.9	3.37
Groundnut meal	274	93	48.1	3.39
Sunflowerseed meal	274	90	23.3	1.75
Rape & mustard meal	274	92	35.6	3.08
Cottonseed meal	274	93	37.9	2.46
Palm kernel meal	274	90	42.9	3.37
Copra meal	274	92	20.7	3.34
Sesameseed meal	274	93	45.5	3.15
Oilseed meal, other	274	90	42.9	3.37
Vegetables	188	92	21.6	2.35
Fruits	349	89	4.6	2.67
Cocoa beans	1,038	87	11.8	2.18
Meat, meat meal & offal	1,322	94	51.4	2.93
Animal fats, including butter	274	100	0.0	9.92
Whey	312	93	13.3	3.33
Milk, excluding butter	312	12	3.3	0.70
Eggs	892	94	51.4	2.93

Feed type	Price (2005 $/T)	Dry matter (%)	Crude protein (%)	Dietary energy (Mcal/kg)
Fish	411	50	32.7	1.86
Fish meal	411	92	65.5	3.20

Oilcrops include soybean, cottonseed, groundnuts, rapeseed, sesame, sunflower, coconuts, palm kernels and other.
Sources: Feed composition from National Research Council (1982); Prices are FAO global average commodity prices from 2004-2006, except for the following: prices for roots and tubers have been adjusted downward to reflect feed quality; wheat price is used for bran; soybean price is used for all oilcrops and meals, vegetable oils, and animal fats; fish and fish meal price are assumed to be 1.5 times the price of soybean.

Table A2. Agricultural Input Cost Shares.

Source Study - country/ region and period of study	Input	Input Cost Shares						Input shares applied to
		1961-70	1971-80	1981-90	1991-00	2001-10	2011-12	
Industrialized countries								
USA (1948-2011)	Labor	0.219	0.170	0.155	0.196	0.203	*0.133*	USA
	Land	0.190	0.212	0.187	0.171	0.147	*0.245*	
Economic Research Service (2014), based on Ball (1985)	Livestock capital	0.111	0.114	0.115	0.102	0.091	*0.077*	
	Fixed capital	0.112	0.117	0.155	0.113	0.112	*0.100*	
	Crop materials	0.175	0.193	0.222	0.274	0.298	*0.274*	
	Livestock materials	0.192	0.194	0.166	0.143	0.150	*0.170*	
Canada (1961-2006)	Labor	0.345	0.406	0.303	0.431	0.349	*0.349*	Canada
	Land	0.035	0.023	0.022	0.016	0.016	*0.016*	
Cahill and Rich (2012)	Livestock capital	0.009	0.007	0.005	0.004	0.005	*0.005*	
	Fixed capital	0.146	0.147	0.162	0.087	0.085	*0.085*	
	Crop materials	0.223	0.211	0.279	0.262	0.328	*0.328*	
	Livestock materials	0.242	0.206	0.229	0.200	0.217	*0.217*	
Australia (1978-2009) ^	Labor	0.176	0.176	0.093	0.088	0.099	*0.099*	Australia and New Zealand
	Land	0.349	0.349	0.600	0.661	0.541	*0.541*	
Zhao *et al.* (2012) with Butzer *et al.* (2012) decomposition of total capital stock	Livestock capital	0.182	0.182	0.110	0.085	0.136	*0.136*	
	Fixed capital	0.137	0.137	0.096	0.065	0.081	*0.081*	
	Crop materials	0.115	0.115	0.074	0.076	0.105	*0.105*	
	Livestock materials	0.041	0.041	0.026	0.025	0.039	*0.039*	
Japan (1880-1985)	Labor	0.388	0.351	0.313	0.313	*0.313*	*0.313*	Japan
	Land	0.288	0.224	0.200	0.200	*0.200*	*0.200*	
Van der Meer and Yamada (1990)	Livestock capital	0.024	0.028	0.026	0.026	*0.026*	*0.026*	
	Fixed capital	0.113	0.165	0.195	0.195	*0.195*	*0.195*	
	Crop materials	0.077	0.107	0.117	0.117	*0.117*	*0.117*	
	Livestock materials	0.110	0.125	0.149	0.149	*0.149*	*0.149*	

Source Study - country/ region and period of study	Input	Input Cost Shares						Input shares applied to
		1961-70	1971-80	1981-90	1991-00	2001-10	2011-12	
Korea-Taiwan (1914-1971; 1971-2007)	Labor	0.374	0.558	0.349	0.208	0.156	*0.156*	South Korea and Taiwan
	Land	0.417	0.227	0.392	0.506	0.519	*0.519*	
1961-70 is average for Korea and Taiwan from Hayami *et al.* (1979); 1970+ from Kwon (2010) using Korea data	Livestock capital	0.020	0.004	0.009	0.010	0.012	*0.012*	
	Fixed capital	0.010	0.016	0.040	0.080	0.122	*0.122*	
	Crop materials	0.130	0.097	0.105	0.098	0.096	*0.096*	
	Livestock materials	0.049	0.097	0.105	0.098	0.096	*0.096*	
United Kingdom (1952-2005)	Labor	0.327	0.164	0.136	0.137	*0.137*	*0.137*	United Kingdom
	Land	0.084	0.126	0.179	0.216	*0.216*	*0.216*	
Thirtle, Piesse and Schimmelpfennig (2008)	Livestock capital	0.031	0.052	0.050	0.060	*0.060*	*0.060*	
	Fixed capital	0.183	0.199	0.202	0.204	*0.204*	*0.204*	
	Crop materials	0.220	0.281	0.235	0.176	*0.176*	*0.176*	
	Livestock materials	0.155	0.178	0.199	0.209	*0.209*	*0.209*	
Europe, Northern except UK (1972-2002) ^	Labor	0.339	0.339	0.251	0.243	0.229	*0.229*	Northern Europe except United Kingdom
	Land	0.043	0.043	0.082	0.082	0.080	*0.080*	
Ball *et al.* (2010); capital decomposition from Butzer *et al.* (2012)	Livestock capital	0.020	0.020	0.026	0.017	0.014	*0.014*	
	Fixed capital	0.075	0.075	0.111	0.141	0.143	*0.143*	
	Crop materials	0.243	0.243	0.254	0.251	0.265	*0.265*	
	Livestock materials	0.280	0.280	0.276	0.265	0.268	*0.268*	
Europe, Southern (1973-2002) ^	Labor	0.539	0.539	0.403	0.388	0.443	*0.443*	Southern Europe
	Land	0.073	0.073	0.112	0.136	0.089	*0.089*	
Ball *et al.* (2010); capital decomposition from Butzer *et al.* (2012)	Livestock capital	0.019	0.019	0.022	0.016	0.012	*0.012*	
	Fixed capital	0.072	0.072	0.094	0.130	0.121	*0.121*	
	Crop materials	0.141	0.141	0.207	0.148	0.139	*0.139*	
	Livestock materials	0.155	0.155	0.161	0.182	0.195	*0.195*	
South Africa (1947-1992)	Labor	0.232	0.210	0.166	0.161	*0.161*	*0.161*	South Africa
	Land	0.129	0.143	0.169	0.144	*0.144*	*0.144*	
Schimmelpfennig *et al.* (2000)	Livestock capital	0.043	0.018	0.010	0.035	*0.035*	*0.035*	
	Fixed capital	0.252	0.230	0.237	0.239	*0.239*	*0.239*	
	Crop materials	0.246	0.279	0.275	0.274	*0.274*	*0.274*	
	Livestock materials	0.098	0.120	0.143	0.147	*0.147*	*0.147*	
Developing countries & regions								
Sub-Saharan Africa (1961-2008)	Labor	0.248	0.248	0.248	0.248	0.248	*0.248*	Sub Saharan Africa
	Land	0.315	0.315	0.315	0.315	0.315	*0.315*	
Fuglie (2011)	Livestock capital	0.308	0.308	0.308	0.308	0.308	*0.308*	
	Fixed capital	0.024	0.024	0.024	0.024	0.024	*0.024*	
	Crop materials	0.055	0.055	0.055	0.055	0.055	*0.055*	
	Livestock materials	0.049	0.049	0.049	0.049	0.049	*0.049*	
Mexico (1960-1991)	Labor	0.257	0.240	0.119	0.115	*0.115*	*0.115*	Central America & Caribbean
	Land	0.505	0.352	0.179	0.225	*0.225*	*0.225*	
Fernandez-Cornejo and Shumway (1997)	Livestock capital	0.089	0.161	0.315	0.263	*0.263*	*0.263*	
	Fixed capital	0.089	0.161	0.315	0.263	*0.263*	*0.263*	
	Crop materials	0.031	0.027	0.017	0.045	*0.045*	*0.045*	
	Livestock materials	0.029	0.059	0.056	0.090	*0.090*	*0.090*	

Source Study - country/ region and period of study	Input	Input Cost Shares						Input shares applied to
		1961-70	1971-80	1981-90	1991-00	2001-10	2011-12	
Brazil (1970, 1985, 1996, 2006) Unpublished estimates provided by Nicholas Rada, calculated from Brazilian Agricultural Censuses	Labor	0.434	0.434	0.443	0.415	0.373	*0.373*	South America, North Africa and West Asia
	Land	0.342	0.342	0.159	0.115	0.083	*0.083*	
	Livestock capital	0.096	0.096	0.090	0.070	0.053	*0.053*	
	Fixed capital	0.071	0.071	0.110	0.177	0.161	*0.161*	
	Crop materials	0.027	0.027	0.120	0.112	0.255	*0.255*	
	Livestock materials	0.030	0.030	0.078	0.111	0.076	*0.076*	
China (1952-1992) Fan and Zhang (2002)	Labor	0.443	0.396	0.413	0.333	*0.333*	*0.333*	China, Mongolia, and North Korea
	Land	0.250	0.209	0.178	0.258	*0.258*	*0.258*	
	Livestock capital	0.210	0.222	0.207	0.190	*0.190*	*0.190*	
	Fixed capital	0.021	0.021	0.087	0.074	*0.074*	*0.074*	
	Crop materials	0.038	0.064	0.084	0.121	*0.121*	*0.121*	
	Livestock materials	0.038	0.039	0.031	0.023	*0.023*	*0.023*	
India (1956-1987; 1980-2008) * Evenson *et al.* (1999); Rada (2013)	Labor	0.406	0.419	0.564	0.554	0.505	*0.505*	South Asia
	Land	0.314	0.210	0.173	0.181	0.267	*0.267*	
	Livestock capital	0.213	0.269	0.123	0.115	0.052	*0.052*	
	Fixed capital	0.003	0.010	0.024	0.043	0.065	*0.065*	
	Crop materials	0.014	0.042	0.066	0.047	0.044	*0.044*	
	Livestock materials	0.050	0.050	0.050	0.060	0.067	*0.067*	
Indonesia (1961-2006) Fuglie (2010a)	Labor	0.370	0.538	0.476	0.388	0.392	*0.392*	Southeast Asia and Pacific
	Land	0.219	0.195	0.188	0.306	0.329	*0.329*	
	Livestock capital	0.327	0.166	0.221	0.160	0.120	*0.120*	
	Fixed capital	0.018	0.020	0.004	0.010	0.015	*0.015*	
	Crop materials	0.033	0.048	0.054	0.045	0.046	*0.046*	
	Livestock materials	0.033	0.033	0.057	0.091	0.098	*0.098*	
Transition countries & regions								
USSR, European (1965-1990; 1992-1999) Lerman *et al.* (2003); Cungu and Swinnen (2003)	Labor	0.104	0.104	0.104	0.190	*0.190*	*0.190*	European states of the former Soviet Union and formerly communist countries of eastern Europe
	Land	0.257	0.257	0.257	0.230	*0.230*	*0.230*	
	Livestock capital	0.183	0.183	0.183	0.170	*0.210*	*0.210*	
	Fixed capital	0.043	0.043	0.043	0.090	*0.090*	*0.090*	
	Crop materials	0.143	0.143	0.143	0.070	*0.070*	*0.070*	
	Livestock materials	0.270	0.270	0.270	0.250	*0.210*	*0.210*	
USSR, Asia (1965-1990; 1992-1999) Lerman *et al.* (2003); Cungu and Swinnen (2003)	Labor	0.194	0.194	0.194	0.190	*0.190*	*0.190*	Irrigation-dependent Asian states of the former Soviet Union
	Land	0.210	0.210	0.210	0.230	*0.230*	*0.230*	
	Livestock capital	0.054	0.054	0.054	0.300	*0.270*	*0.270*	
	Fixed capital	0.113	0.113	0.113	0.090	*0.090*	*0.090*	
	Crop materials	0.379	0.379	0.379	0.070	*0.070*	*0.070*	
	Livestock materials	0.050	0.050	0.050	0.120	*0.150*	*0.150*	

* Evenson *et al.* (1999) and Rada (2013) do not report a cost share for animal feed for India. To derive the feed cost share for India, I estimated total feed costs from FAO commodity balance sheets on feed utilization and divided this by FAO gross agricultural output (both valued at FAO international prices for 2004-2006). I then subtracted the feed cost share from the livestock capital cost share reported in the Evenson et al. (1999) and Rada (2013) studies so that the input shares sum to 1.00.

^ When studies did not report fixed capital separately from livestock capital, average capital component shares for high-income, middle income, and low-income countries from Butzer *et al.* (2012) were used to divide total capital into these components.

Cost shares in italics are extrapolations using estimates from the nearest period available.

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 A3. Countries and Regional Groupings Included in the Productivity Analysis.

Sub-Saharan Africa (SSA) (developing)						
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[b]	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		
				Swaziland		
				Zambia		
				Zimbabwe		
Latin America & Caribbean (LAC) (developing)					**N. America**	**Africa**
Northeast	*Andes*	*S. Cone*	*C. America*	*Caribbean*	*Developed*	*Developed*
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	L. Antilles[a]		
			Nicaragua	Puerto Rico		
			Panama	Trin. & Tob.		
Asia-Pacific					**West Asia & North Africa**	
Developed	*South Asia*	*SE Asia*	*Pacific*	*NE Asia*	*West Asia*	*North Africa*
Japan	Afghanistan	Brunei	Fiji	China	Bahrain	Algeria
Korea, Rep.	Bhutan	Cambodia	Micronesia[a]	Korea, DPR	Iran	Egypt
Taiwan	Nepal	Indonesia	N. Caledonia	Mongolia	Iraq	Libya
Singapore	Sri Lanka	Laos	PNG		Israel	Morocco
	Bangladesh	Malaysia	Polynesia[a]		Jordan	Tunisia
	India	Myanmar	Solomon Is.		Kuwait	
	Pakistan	Philippines	Vanuatu		Lebanon	Syria
		Thailand			Oman	Turkey
		Viet Nam			Qatar	UAR
					S. Arabia	Yemen

Oceania	**Europe Developed**		**Europe**	**Former Soviet Union (transition)**		
Developed	*Northern*	*Southern*	*Transition*	*Baltic*	*E. Europe*	*CAC*
Australia	Austria	Cyprus	Albania	Estonia	Belarus	Armenia
N. Zealand	Belgium-Lux.	Greece	Bulgaria	Latvia	Kazakhstan	Azerbaijan
	Denmark	Italy	Czecho-	Lithuania	Moldova	Georgia
	Finland	Malta	slovakia[b]		Russia	Kyrgyzstan
	France	Portugal	Hungary		Ukraine	Tajikistan
	Germany	Spain	Poland			Turkmenistan
	Iceland		Romania			Uzbekistan
	Ireland	Sweden	Yugoslavia[b]			
	Netherlands	Switzerland				
	Norway	UK				

CAC = Central Asia & Caucasia.
a Composite territories composed of several small island nations.
b Statistics from the successor states of Ethiopia (Ethiopia and Eritrea), Sudan (Sudan and South Sudan), Czechoslovakia (Czech and Slovak Republics), and Yugoslavia (Slovenia, Croatia, Bosnia, Macedonia, Serbia and Montenegro) were merged to form continuous geographical coverage since 1961.