CHAPTER 4

Total Factor Productivity in the Global Agricultural Economy: Evidence from FAO Data

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1. INTRODUCTION

Recent assessments of the global agricultural economy have expressed concerns of a significant slowing down in productivity growth, which raises the specter of heightened supply-side constraints at a time when population, income, and energy drivers are raising agricultural demand. The *World Bank Development Report 2008* identified a halving of the growth rate in grain yields in developing countries between 1970-1989 and 1990-2005 (World Bank 2007). Case studies in this volume from the United States (Chapter 8), Australian broadacre agriculture (Chapter 5), and the Canadian Prairie Provinces (Chapter 6) report a slowing of the growth rate in agricultural total factor productivity (TFP) in these regions. Yet, evidence from major developing countries such as Brazil (Avila 2007; Gasquez, Bastos, and Bacchi 2008) and China (Chapter 9 in this volume) suggest productivity growth has accelerated there. This contrasts with earlier studies of global productivity growth, which found agricultural land and labor

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The author would like to thank Eldon Ball, David Schimmelpfennig, José Garcia Gasques, and Shenggan Fan for making available unpublished data for this study, and Julian Alston for helpful comments on an earlier draft of the chapter. The usual disclaimers apply.

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productivity rising faster in developed than in developing countries (Hayami and Ruttan 1985; Craig, Pardey, and Roseboom 1997). Another confounding factor is the uneven performance of agriculture in the transition countries of the former Soviet block (Chapter 10 of this volume). Thus, the national and regional evidence is mixed on recent trends in agricultural productivity. The purpose of this chapter is to present a comprehensive global and regional picture of agricultural TFP growth between 1961 and 2007. This assessment relies heavily on data from the Food and Agriculture Organization (FAO) of the United Nations (in some cases supplemented with data from national sources), and draws upon the findings of several country-level case studies of agricultural TFP for input cost-share information to construct a model of global agricultural productivity growth.

The necessary ingredients for an assessment of agricultural TFP are measures of aggregate outputs and inputs and their economic values. To measure output growth in global agriculture, I use the FAO output index, which is a Laspeyres index valuing about 195 crop and livestock commodities at a fixed set of average global prices (Rao 1993). Periodically, the FAO brings together national-level commodity price data to construct a globally representative set of prices weighted by the Stone-Geary method. It then uses these prices to construct agricultural output indexes for each country of the world. Its latest price update is for the 1999-2001 period, expressed in 2000 U.S. dollars. Although prices differ over time and across space, the important feature of commodity prices for output index construction is their value relative to each other, which, given substitution possibilities, tends to be fairly stable over time. Thus, the growth rate in agricultural output reported by an individual country (using annual domestic price data appropriately deflated) is generally close to the growth rate in the FAO output index for that country. It should be noted, however, that changes in real output often differ substantially from changes in the World Bank's estimates of real agricultural value-added, or gross domestic product (GDP). Agricultural GDP is estimated by taking agricultural output net of feed and seed, valued at current national prices, and then subtracting payments for materials provided by other sectors (e.g., fertilizers, chemicals, and energy). Deflating this value by a general price index introduces terms-of-trade effects into the output series: if agricultural prices are changing faster than the average price level in the whole economy, then that will be reflected in the rate of change in agricultural GDP. The FAO output price series is a better measure of changes in the real economy since it does not include these terms-of-trade effects.

The major challenge in using FAO data for assessing changes in agricultural TFP is measuring changes in aggregate input in a consistent fashion. Since TFP is usually defined as the ratio of aggregate output to aggregate input (i.e., as the average product of aggregate input), it is necessary to account somehow for the sum total of changes of services of land, labor, capital, and material inputs used in production. The "growth accounting" method measures aggregate input growth as the weighted sum of the growth rates of the quantities of the individual factors of production, wherein the weights are the cost shares. But for most countries of the world we lack representative data on input prices and therefore cost shares. This is especially true for developing countries where the most important inputs are farm-supplied, like land and labor, but where wage labor and land rental markets are thin, thus making it difficult to assess the share of these inputs in total costs.

To circumvent the lack of price or cost data, most previous assessments of global agricultural TFP have relied on distance function measures like the Malmquist index to compare productivity among groups of countries. Distance functions are derived from input-output relationships based on quantity data only. Recently, Ludena et al. (2007) used this method to estimate agricultural productivity growth for 116 countries and found that average annual agricultural TFP growth increased from 0.60% during 1961-1980 to 1.29% during 1981-2000. But this methodology is sensitive to the set of countries included for comparison and the number of variables in the model, or the dimensionality issue (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 does not seem plausible.

In this chapter I bring together several country-level case studies that have acquired representative input cost data to construct Tornqvist-Theil growth accounting indexes of agricultural TFP growth and apply their average cost-share estimates to other countries with similar agriculture in order to construct aggregate input indexes for these countries. For some regions for which reliable input cost data are not available (namely, Sub-Saharan Africa and the countries of the former Soviet Union), I use econometrically estimated input production elasticities as weighting factors for input growth aggregation. Theoretically, production elasticities and corresponding cost shares should be equal, so long as producers maximize profit and markets are in long-run competitive equilibrium. With growth rates in aggregate output and input thus constructed, I derive growth rates in agricultural TFP by country, region, and for the world as a whole for each year from 1961 to 2007.

In the next section of the chapter I discuss the methodology and sources of data in more detail. In particular, I describe a method of adjusting agricultural land area for quality differences to obtain a better accounting of changes in "effective" agricultural land over time. I then present results of the model, showing how input accumulation and input (total factor) productivity have contributed to agricultural output growth over time, in the global and regional agricultural economies.

2. MEASURING TOTAL FACTOR PRODUCTIVITY IN AGRICULTURE

2.1 Methods for TFP Measurement

Productivity statistics compare changes in outputs to changes in inputs in order to assess the performance of a sector. Two types of productivity measures are partial and multifactor indexes. Partial productivity indexes relate output to a single input, such as labor or land. These measures are useful for indicating factor-saving biases in technical change but are likely to overstate the overall improvement in efficiency because they do not account for changes in other input use. For example, rising output per worker may follow from additions to the capital stock, and higher crop yield may be due to greater application of fertilizer. For this reason, a measure of TFP relating output to all of the inputs used in production gives a superior indicator of a sector's efficiency than do indexes of partial productivity.

TFP is usually defined as the ratio of total output to total inputs in a production process. In other words, TFP measures the average product of all inputs. Let total output be given by *Y* and total inputs by *X*. Then TFP is simply

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

Taking logarithmic differentials of equation (1) with respect to time, *t,* yields

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

which simply states that, for small changes, the rate of change in TFP is equal to the difference between the rate of change in aggregate output and the rate of change in aggregate input.

In agriculture, output is composed of multiple commodities produced by multiple inputs in a joint production process, so **Y** and **X** are vectors. Chambers (1988) showed that when the underlying technology can be represented by a Cobb-Douglas production function and where (i) producers maximize profits and (ii) markets are in long-run competitive equilibrium (total revenue equals total cost), then equation (2) can be written as

$$\ln\left(\frac{TFP_t}{TFP_{t-1}}\right) = \sum_i R_i \ln\left(\frac{Y_{i,t}}{Y_{i,t-1}}\right) - \sum_j S_j \ln\left(\frac{X_{j,t}}{X_{j,t-1}}\right) \qquad (3)$$

where R_i is the revenue share of the *i*th output and S_j is the cost share of the *j*th input. Output growth is estimated by summing over the output growth rates for each commodity after multiplying each by its revenue share. Similarly, input growth is found by summing the growth rate of each input, weighting each by its cost share. TFP growth is just the difference between the growth in aggregate output and the growth in aggregate input. The principal difference between this measure of TFP growth and theoretically preferred measures like the Tornqvist-Theil index is that a Tornqvist-Theil index takes account of the fact that cost and revenue shares vary over time. Using fixed revenue and factor shares results in "index number bias" in cases in which either the revenue or the cost shares are changing significantly. But the extent of the bias is usually unknown. It should be pointed out as well that cost shares are partly dependent on output prices themselves, since a part of agricultural output is used as inputs (seed and feed) in production.

A key limitation in using equation (3) for measuring agricultural productivity change is that we lack data on input cost shares for most countries. There is simply no internationally comparable information on input prices, especially for inputs that may not be widely exchanged in the market such as farm land and labor. 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 (Coelli and Rao 2005). But this method is sensitive to aggregation issues as well as data quality (especially differences in agricultural land quality across countries) and can give unbelievably high or negative growth rates. To address this problem, I use the approach originally suggested by Avila and Evenson (2004). They constructed careful estimates of input cost shares for two large developing countries (India and Brazil) from agricultural census surveys and from these derived representative cost shares for other developing countries. I extend this approach by assembling cost-share estimates for seven additional countries (China, Indonesia, Mexico, South Africa, Japan, the United Kingdom, and the United States) and then assume that these cost shares are representative of agricultural production for different groups of countries. For two global regions, Sub-Saharan Africa and the former Soviet Union, in place of cost shares I use econometrically estimated production elasticities (with constant returns to scale imposed) as weights for input aggregation. I describe this more thoroughly in the section on "input cost shares."

To summarize, the theory underpinning the TFP productivity index assumes that producers maximize profits so that the elasticity of output with respect to each input is equal to its factor share. It also assumes that markets are in long-run competitive equilibrium (where technology exhibits constant returns to scale) so that total revenue equals total cost. If these conditions hold and the underlying production function is Cobb-Douglas, then this index provides an exact representation of Hicks-neutral technical change.

2.2. Output and Input Data

To assess changes in agricultural productivity over time, I use FAO annual data on agricultural outputs and inputs from 1961 to 2007 and in some cases augment these data with updated or improved statistics from other sources.

For output, FAO publishes data on production of crops and livestock and aggregates these data into a production index using a common set of commodity prices from the 1999-2001 period and expresses the index in constant 2000 U.S. dollars. What is important for estimating output growth are the *relative* prices of these commodities (since this determines the weights on the commodity growth rates used for deriving the growth rate for total output). In relative terms, the 1999-2001 FAO commodity prices are fairly close to the "wheat equivalent" prices developed by Hayami and Ruttan (1985, pp. 453-454) in their seminal study on international agricultural productivity (the FAO relative prices have a correlation coefficient of 0.86 with the Hayami-Ruttan wheat-equivalent prices). The FAO index of real output excludes production of forages but includes crop production that may be used for animal feed.

To disentangle long-run trends from short-run fluctuations in output due to weather and other disturbances, I smooth the output series for each country using the Hodrick-Prescott filter setting λ=6.25 for annual data as recommended by Ravn and Uhlig (2002). This filter is commonly used to remove short-run fluctuations from macroeconomic time series in business cycle analysis. However, this process does not completely remove the effects of multiyear shocks such as war or a prolonged drought, so it is still necessary to evaluate observed changes in the rate of TFP growth with auxiliary information about extended periods of unusual weather or other disturbances.

For agricultural inputs, FAO publishes data on cropland (rain-fed 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 whenever available. For fertilizer consumption, the International Fertilizer Association has more up-to-date and more accurate statistics than does 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 (ERS 2009b), with original data coming from the National Bureau of Statistics of China (2006). For Brazil, I use results of the recently published 2006 Brazilian agricultural census (IPGE 2008), and for Indonesia, I compiled improved data on agricultural land and machinery use (Fuglie 2004, 2010). For Taiwan, I use statistics from the Council of Agriculture. Finally, since FAO reports data on countries that made up the former Soviet Union 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-1991 years (Lerman et al. 2003; Swinnen, Dries, and Macours 2005), I use Eurostat data for the Baltic states and Eastern Europe, CISSTAT data for other former SSRs except Ukraine, and the International Labor Organization's LABORSTA database for Ukraine for estimates of the size of the agricultural labor force since 1990.

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 rain-fed 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 2009 for a discussion of why this series appears to be a better measure of agricultural land in this region). I also derive a quality-adjusted measure of agricultural land 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 based on Hayami and Ruttan (1985, p. 450) are as follows: 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 equivalents. *Farm machinery* is the number of riding tractors in use. All of these series are available through 2007 except for farm machinery, which ends in 2006. I estimate tractors in use for 2007 by taking the average rate of growth in this variable over 2003-2006, except for China, the United States, and Brazil for which these are from government statistical sources.

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, other farm machinery besides riding tractors, energy, and farm structures. However, data on many of these inputs are available for the nine country case studies I use for constructing the representative 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.

2.3. Land Quality

The FAOSTAT agricultural database provides time-series estimates of agricultural land by country and divides these estimates into cropland (arable and permanent crops) and 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 two recent studies of international agricultural productivity, Craig, Pardey, and Roseboom (1997) and Wiebe et al. (2003) took considerable effort to include in their regression models variables that could account for differences in land quality (such as indexes of average rainfall and soil type, the proportion of irrigated or pastureland in total agricultural land, and fixed-effect models with regional or country dummies), and obtained estimates of production elasticities that were more in line with observed land cost shares.

In this study, because I estimate only productivity growth rather than productivity levels, differences in land quality across countries is less problematic. The estimates depend only on changes in agricultural land and other input use within a country 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 and should therefore be given greater weight in measuring input changes. To account for differences in land type, 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., I use average annual data from the 1961-1965 period). I first construct regional dummy variables ($REGION_i$, i=1,2,…5, representing developed and Former Soviet Union 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 dummy variables allows the coefficients to vary among regions:

$$\ln\left(\frac{Ag\ output}{Cropland + Pasture}\right) = \sum_i a_i\left(RAINFED * REGION_i\right) + \sum_i b_i\left(PASTURE * REGION_i\right) + \sum_i g_i\left(IRRIG * REGION_i\right). \tag{4}$$

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 pastureland. The estimates of the parameters in equation (4) 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.

The results of the regression in equation (4) are shown in Table 4.1. All the coefficients are statistically significant and the variables explain about 75% of the cross-country variability in land productivity. The lower part of the table translates the estimated coefficients into average land productivities in dollars of output per hectare by land type. The results show that, on average, one hectare of irrigated land was more than twice as productive as rain-fed cropland, which in turn was 10-20 times as productive as permanent pasture, with some variation across regions. The results appear to 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). Peterson regressed 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. Moreover, what are important for the growth accounting exercise are only the relative productivities, as these become the quality weights for aggregating land changes within a country.

The effects of this land quality adjustment are shown in Table 4.2. When summed by their raw values, total global agricultural land expanded by about 10% between 1961 and 2007, with nearly all of this expansion occurring in developing countries. When adjusted for quality, "effective" agricultural land expanded by two and a half times this rate. Globally, irrigated cropland expanded

Table 4.1. Estimation of land quality weights

Regression estimates

Variable	Coefficient	Std. Error	t Stat
SSA*rainfed	6.840	0.299	22.868
SSA*pasture	2.674	0.163	16.422
ASIA-OCEANIA*rainfed	6.300	0.239	26.404
ASIA-OCEANIA*pasture	3.427	0.367	9.333
WANA*rainfed	7.024	0.582	12.069
WANA*pasture	3.290	0.267	12.331
LAC*rainfed	7.387	0.411	17.987
LAC*pasture	3.873	0.270	14.329
LDC*irrig	7.396	0.601	12.304
DC*rainfed	7.087	0.280	25.291
DC*pasture	4.725	0.329	14.362
DC*irrig	7.850	1.072	7.325

Note: All coefficients significant at the 1% level.

Regression statistics

Multiple R	0.875
R Square	0.765
Adjusted R Square	0.747
Standard Error	0.752
F-statistic	42.596
Significance of F	0.000
Observations	156

Notes: Dependent variable: log of the average output per hectare of agricultural land (cropland and permanent pasture) during 1961-1965 where output is measured in 1,000s of constant US$ (using 1999-2001 international average prices) according to the FAO value of agricultural output measure SSA=Sub-Saharan Africa; WANA=West Asia & North Africa; LAC=Latin America & Caribbean; LDC=less developed countries; DC=developed countries.
The intercept term was excluded from the regression above. To get a meaningful R-squared, an intercept term was included and one of the other variables dropped from the regression.

Implied average productivities from the regression estimates

Region	Average Productivity of Agricultural Land during 1961-65 ($/ha)			Land Quality Weights Relative to Rain-Fed Cropland		
	Rain-fed	Irrigated	Pasture	Rain-fed	Irrigated	Pasture
Developed countries	1,196	2,566	113	1.000	2.145	0.094
Sub-Saharan Africa	935	1,629	14	1.000	1.743	0.016
Asia-Oceania	544	1,629	31	1.000	2.993	0.057
West Asia-North Africa	1,123	1,629	27	1.000	1.451	0.024
Latin America & Caribbean	1,614	1,629	48	1.000	1.009	0.030

Table 4.2. Global agricultural land-use changes

A. Raw totals (millions of hectares)

	Rain-fed Cropland			Irrigated Cropland			Permanent Pasture			Total Agricultural Land		
Region	1961	2007	% Change	1961	2007	% Change	1961	2007	% Change	1961	2006	% Change
Developed Countries	364	330	-9	27	47	72	886	789	-11	1,277	1,166	-9
Transition Countries	280	220	-22	11	25	126	322	379	18	613	623	2
Developing Countries	592	740	25	99	214	116	1,912	2,206	15	2,603	3,160	21
World	1,235	1,290	4	138	286	108	3,120	3,374	8	4,493	4,949	10

B. Quality adjusted (millions of hectares of "rain-fed cropland equivalents")

	Rain-fed Cropland			Irrigated Cropland			Permanent Pasture			Total Agricultural Land		
Region	1961	2007	% Change	1961	2007	% Change	1961	2007	% Change	1961	2007	% Change
Developed Countries	364	330	-9	58	100	72	76	68	-11	498	498	0
Transition Countries	280	220	-22	24	54	126	30	36	18	334	309	-7
Developing Countries	592	740	25	258	552	114	57	69	20	907	1,360	50
World	1,235	1,290	4	340	706	108	164	172	5	1,739	2,167	25

Sources: Agricultural land area from FAO, except for Brazil, China, and Indonesia, which are drawn from national sources. Land quality adjustments from author's regressions (see text).

by 148 million hectares, and this accounted for virtually all of the change in "effective" agricultural land over this period. For the purpose of our TFP calculation, accounting for the changes in the quality of agricultural land over time should increase the growth rate in aggregate agricultural input and commensurately reduce the estimated growth in TFP.

2.4. Input Cost Shares

To derive input cost shares or production elasticities, I draw upon other studies that reported relatively complete measurements of these items for selected countries and then use these cost estimates as "representative" of agriculture in different regions of the world. In Table 4.3 I show the input cost shares from nine country studies (five developing countries: China, India, Indonesia, Brazil, and Mexico; and four developed countries: Japan, South Africa,[1] the United Kingdom, and the United States) as well as econometric estimates of production elasticities for Sub-Saharan Africa and the former Soviet Union. Table 4.3 also shows the regions to which the various cost-share estimates were applied for constructing the aggregate input indexes. For instance, the estimates for Brazil were applied to South America, West Asia, and North Africa, and the estimates for India were applied to other countries in South Asia. These assignments were based on judgments about the resemblance among the agricultural sectors of these countries. Countries assigned to cost shares from India, for example, tended to be low-income countries using relatively few modern inputs. Countries assigned to the cost shares from Brazil tended to be middle-income countries having relatively large livestock sectors.

While assigning cost shares to countries in this manner may seem fairly arbitrary, an argument in favor is that there is some degree of congruence among the cost shares reported for the country studies shown in Table 4.3. For the developing-country cases (India, Indonesia, China, Brazil, Mexico, and Sub-Saharan Africa), cost shares or production elasticities ranged from 0.31 to 0.46 for labor, 0.22 to 0.29 for land, and 0.14 to 0.33 for livestock, while cost shares for fertilizer and machinery inputs were not more than 14% of total output in

[1]I have classified South Africa as a developed country despite the dualist structure of this country's agriculture, which consists of a "modern" sector of commercial farms and a "peasant" sector of smallholder subsistence-oriented farms. Since 1960, smallholders' share of cropland planted has never exceeded 17%, and, given their prevalence on marginal lands, they account for an even smaller share of agricultural output (Liebenberg, Pardey, and Kahn 2010).

Table 4.3. Agricultural input cost shares or production elasticities used for input aggregation

Study	Country & Period for Estimation	Labor	Land & Structures	Livestock & Feed	Machinery & Energy	Chemicals & Seed	Regions to which Factor Shares Are Assigned	Global Output Share (%)
Developing countries								
Fan & Zhang 2002	China 1961-97	0.40	0.22	0.23	0.06	0.09	NE Asia developing	16.7
Evenson, Pray, & Rosegrant 1999	India 1967, 77, 87	0.46	0.23	0.25	0.01	0.04	South Asia	11.6
Fuglie 2010	Indonesia 1961-06	0.46	0.25	0.22	0.01	0.05	SE Asia, Oceania developing	5.3
Avila & Evenson 1995	Brazil 1970, 90	0.43	0.22	0.14	0.14	0.07	South America, WANA	12.7
Hertford 1971	Mexico 1940-65	0.38	0.29	0.19	0.07	0.07	Central America, Caribbean	2.4
Fuglie 2009	Sub-Saharan Africa[a] 1961-06	0.31	0.28	0.33	0.02	0.05	Sub-Saharan Africa	5.0
Developed countries								
ERS 2009a, based on Ball et al. 1997	USA 1961-04	0.20	0.19	0.28	0.14	0.18	North America, Australia & NZ	15.6
Thirtle & Bottomley 1992	UK 1967-90	0.30	0.17	0.26	0.17	0.10	Northwest Europe, Southern Europe	14.4

Table 4.3. Continued

Study	Country & Period for Estimation	Labor	Land & Structures	Livestock & Feed	Machinery & Energy	Chemicals & Seed	Regions to which Factor Shares Are Assigned	Global Output Share (%)
Van der Meer & Yamada 1990	Japan 1965-80	0.39	0.23	0.10	0.05	0.23	Asia developed	2.3
Thirtle, Sartorius von Bach, & van Zyl 1993	South Africa 1961-92	0.23	0.17	0.17	0.27	0.17	South Africa	0.60
Transition economies: Former Soviet Union (FSU) and Eastern Europe (EE)[a,b]								
Lerman et al. 2003	Rainfed SSR 1965-90	0.10	0.26	0.45	0.04	0.14	SSR (rain-fed) & EE, pre-1992	12.6
	Irrigated SSR 1965-90	0.19	0.21	0.10	0.11	0.38	SSR (irrigated), pre-1992	1.0
Cungo & Swinnen 2003	FSU and EE 1992-99	0.19	0.23	0.42	0.09	0.07	FSU and EE, 1992 and after	13.5
World		0.35	0.21	0.23	0.10	0.10	Average, weighted by output shares	100.0

[a]These studies estimated production elasticities rather than factor shares.

[b]For transition economies, separate factor shares are used for the pre-transition and post-transition periods. For years prior to 1992, Lerman et al. (2003) estimated production elasticities for Soviet Socialist Republics (SSR) relying primarily on rain-fed agriculture and those with primarily irrigated cropland. Irrigated SSRs include Azerbaijan, Armenia, Georgia, Uzbekistan, Kyrgyzstan, Tajikistan, and Turkmenistan. Rain-fed SSRs include the seven European SSRs and Kazakhstan. These coefficients are also applied to Eastern European transition economies for these years. Cungo and Swinnen (2003) estimated production elasticities using data from all 15 SSRs and 8 Eastern European countries from 1992- to 1999. These are applied to all transition economies for the years 1992-2007.

any of the countries. There was a tendency for the labor cost share to fall and the fertilizer and machinery cost shares to rise with the level of agricultural development, reflecting embodiment of new technology in these inputs and substitution for labor. The nine countries and two regions for which direct estimates of cost shares or production elasticities are observed are also relatively large producers, together accounting for two-thirds of global agricultural output in 2005-2007, according to the FAO data.

2.5. Limitations

Some limitations of these calculations should be noted, given the nature of the data on which they are based. The first limitation is that I only compute rates of change in TFP. TFP "levels" cannot be compared across countries with this method. A second limitation is that I do not make adjustments for input quality changes other than for land. A third limitation is that revenue and cost shares are held constant over time. However, an examination of the output data shows that for major commodity categories (cereal crops, oil crops, fruits and vegetables, meat, milk, etc.), the global output growth rates were similar over the 1961-2007 period. On the input side there has been more movement in cost shares among the major categories, but these changes occur gradually over decades. Thus, the likelihood of major biases in productivity measurement over a decade or two is not large, although this does remain a potential source of bias for longer-term comparisons. The principal advantage of these TFP growth estimates, however, is that the calculations have a standardized quality. I use a common method, a common period of time, and a consistent set of definitions for determining aggregate input and output for all countries. Moreover, I include 171 countries in the assessment, a nearly complete accounting of global agricultural production of crops and livestock.[2] I assess growth in individual countries as well as regions, and while regional averages may mask differences in performance among the

[2]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 were aggregated in order to make comparisons with productivity before Yugoslavia's dissolution; data were aggregated similarly for Czechoslovakia and Ethiopia. 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, respectively. This also enables a more detailed examination of regional patterns of agricultural productivity growth. The only countries or regions not included in the analysis are the Palestinian Territories, Western Sahara, Greenland, Liechtenstein, Andorra, and a number of very small urban or island states and dependencies.

countries within a region, the choice of aggregation into regions does not affect individual country results, unlike distance function measures. See Table 4.4 for a complete list of countries included in the analysis and their regional groupings.

3. RESULTS

As a gauge of how well the described approach captures the main movements in agricultural productivity, it is useful to compare results with those of country-level case studies that estimated agricultural TFP using Tornqvist-Theil index methods. As a general rule the results of these country case studies should be viewed as superior because they (i) employ a richer set of country-level data (especially using national rather than global prices), (ii) allow revenue and cost shares to vary over time (rather than holding shares fixed), and (iii) use a more disaggregated set of inputs or other means to control for changes in input quality over time. Table 4.5 compares the average annual growth rates in agricultural output, input, and TFP between eight country-level studies and the results found here, estimated over the same period of time. Figure 4.1 plots the TFP indexes from the referenced studies (solid line) and the present study (dashed line) for the six largest countries. In spite of the data and the methodological differences, my results conform remarkably well to the estimates reported in the country studies. For four of the eight countries there are no significant differences in the growth estimates for agricultural output, input, or TFP. In another three cases (Brazil, Mexico, and China), my estimates of TFP growth were significantly lower than those of the country studies. My results show slightly slower output growth and slightly faster input growth (neither significantly different from the country studies), but the compounded effect of these differences caused the TFP growth rates to vary more than the critical value of a means difference test. Nevertheless, both my results and those of the country studies find that the TFP growth of Brazil and China was in the “high” range and that of Mexico was in a mid-range relative to the global economy. Finally, for India my results show significantly higher input growth, but output and TFP growth are very similar to the Tornqvist-Theil index estimated for this country. The similarity of my results with those of the country studies strengthens my confidence in the results for global agricultural productivity trends in what follows.

Table 4.6 shows a set of productivity indicators for the global agricultural economy over the 1961-2007 period and by decade. Global indexes are derived

Table 4.4. Countries and regional groupings included in the productivity analysis

Sub-Saharan Africa						
Central	**Eastern**	**Horn**	**Sahel**	**Southern**	**Western**	**Nigeria**
Cameroon	Burundi	Djibouti	Burkina Faso	Angola	Benin	
CAR	Kenya	Ethiopia[b]	Cape Verde	Botswana	Côte d'Ivoire	
Congo	Rwanda	Somalia	Chad	Comoros	Ghana	
Congo, DR	Seychelles	Sudan	Gambia	Lesotho	Guinea	
Eq. Guinea	Tanzania		Mali	Madagascar	Guinea Bissau	
Gabon	Uganda		Mauritania	Malawi	Liberia	
ST & P			Niger	Mauritius	Sierra Leone	
			Senegal	Mozambique	Togo	
				Namibia		
				Réunion		
				Swaziland		
				Zambia		
				Zimbabwe		
Latin America & Caribbean					**North**	**Africa,**
Northeast	**Andes**	**S. Cone**	**C. America**	**Caribbean**	**America**	**Developed**
Brazil	Bolivia	Argentina	Belize	Bahamas	Canada	South Africa
French Guiana	Colombia	Chile	Costa Rica	Cuba	United States	
Guyana	Ecuador	Paraguay	El Salvador	Dominican Rep.		
Suriname	Peru	Uruguay	Guatemala	Haiti		
	Venezuela		Honduras	Jamaica		
			Mexico	Lesser Antilles[a]		
			Nicaragua	Puerto Rico		
			Panama	Trin. & Tob.		

Table 4.4. Continued

Asia				**Former Soviet Union**		
Developed	**NE Asia, developing**	**Southeast 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		Russian Fed.	Kyrgyzstan
		Malaysia	Bangladesh		Ukraine	Tajikistan
		Myanmar	India			Turkmenistan
		Philippines	Pakistan			Uzbekistan
		Thailand				
		Timor Leste				
		Viet Nam				
Europe			**West Asia & North Africa**		**Oceania**	
Northwest	**Southern**	**Transition**	**North Africa**	**West Asia**	**Developed**	**Developing**
Austria	Cyprus	Albania	Algeria	Bahrain	Australia	Fiji
Belgium-Lux.	Greece	Bulgaria	Egypt	Iran	New Zealand	Micronesia [a]
Denmark	Italy	Czechoslovakia[b]	Libya	Iraq		New Caledonia
Finland	Malta	Hungary	Morocco	Israel		PNG
France	Portugal	Poland	Tunisia	Jordan		Polynesia [a]
Germany	Spain	Romania		Kuwait		Solomon Is.
Iceland		Yugoslavia[b]		Lebanon		Vanuatu
Ireland				Oman		
Netherlands				Qatar		
Norway				Saudi Arabia		
Sweden				Syria		
Switzerland				Turkey		
UK				UAR		
				Yemen		

[a]Composite countries composed of several small island nations.

[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 2007.

Table 4.5. Comparison of agricultural growth estimates between country studies and the present study

Country	Study	Period	Type	Mean Annual Growth (%) Country Study	My Estimate	Difference	t-value	
Brazil	Gasquez, Bastos, and Bacchi 2008	1975-2007	Input	0.57	0.95	-0.38	-1.59	ns
			Output	3.83	3.75	0.08	0.31	ns
			TFP	3.26	2.80	0.47	3.34	***
Mexico	Fernandez-Cornejo & Shumway 1997	1961-1991	Input	1.37	1.79	-0.42	-1.76	ns
			Output	3.69	3.28	0.41	1.53	ns
			TFP	2.32	1.48	0.84	5.98	***
China	Fan and Zhang 2002	1961-1997	Input	2.05	2.59	-0.54	-2.24	ns
			Output	4.67	4.41	0.26	0.96	ns
			TFP	2.62	1.82	0.80	5.71	***
India	Fan, Hazell, and Thorat 1999	1970-1994	Input	0.86	1.59	-0.72	-3.01	***
			Output	2.61	3.12	-0.52	-1.90	ns
			TFP	1.74	1.54	0.21	1.48	ns
Indonesia	Fuglie 2010	1961-2005	Input	1.83	1.82	0.01	0.04	ns
			Output	3.66	3.49	0.18	0.65	ns
			TFP	1.84	1.67	0.17	1.18	ns
South Africa	Thirtle, Sartorius von Bach, and van Zyl 1993	1961-1992	Input	1.02	0.62	0.39	1.63	ns
			Output	2.44	1.91	0.53	1.94	ns
			TFP	1.42	1.29	0.14	0.97	ns

Table 4.5. Continued

				Mean Annual Growth (%)				
Country	Study	Period	Type	Country Study	My Estimate	Difference	t-value	
EU-11	Derived from Ball et al. (forthcoming) [a]	1973-2002	Input	-0.44	-0.91	0.47	1.93	ns
			Output	1.32	0.86	0.46	1.69	ns
			TFP	1.76	1.77	-0.01	-0.05	ns
United States	ERS 2009a based on Ball et al. 1997	1961-2006	Input	-0.09	0.16	-0.25	-1.03	ns
			Output	1.54	1.57	-0.03	-0.10	ns
			TFP	1.63	1.41	0.22	1.57	ns

***,**,* indicate significant differences between the means at the 1%, 5%, and 10% significance levels, respectively; "ns" indicates the difference between the means is not significant.

[a] Ball et al. (forthcoming) reports agricultural TFP indexes for 11 members of the European Union (the UK, Ireland, France, Germany, Holland, Spain, Italy, Sweden, Denmark, Greece, and Finland). I form an EU-11 weighted average TFP index using country revenue shares as weights.

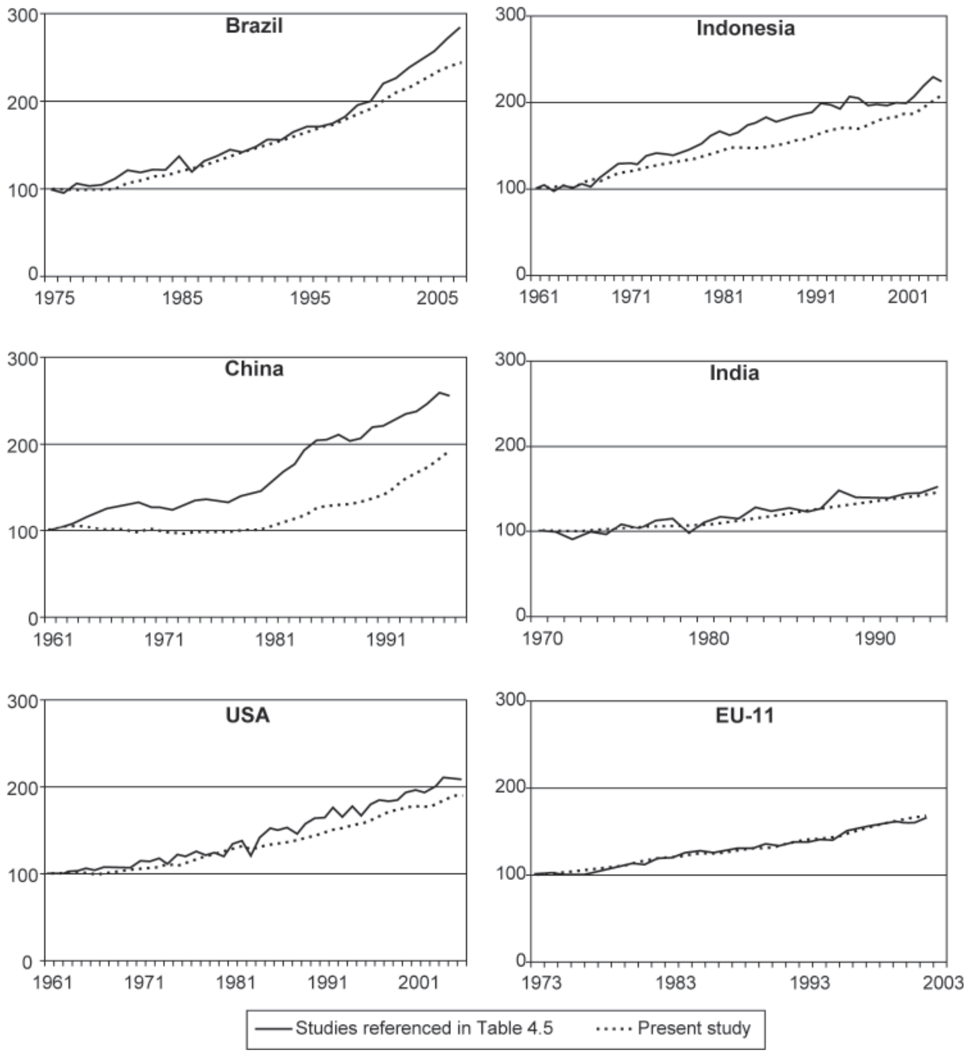

Figure 4.1. Comparison of agricultural TFP indexes (index equals 100 in initial year)

Table 4.6. Productivity indicators for world agriculture

Average Annual Growth Rate by Period (%)	Output	Input	TFP	Output per Worker	Output per Hectare	Grain Yield (t/ha)
1961-1969	2.81	2.31	0.49	0.96	2.39	2.84
1970-1979	2.23	1.60	0.63	1.46	2.21	2.62
1980-1989	2.13	1.21	0.92	0.97	1.72	2.00
1990-1999	2.01	0.47	1.54	1.15	1.74	1.61
2000-2007	2.08	0.74	1.34	1.72	2.10	1.01
1970-1989	2.18	1.40	0.77	1.22	1.97	2.31
1990-2007	2.04	0.59	1.45	1.40	1.90	1.35
1961-2007	2.23	1.24	0.99	1.25	2.01	2.02

Sources: FAOSTAT and author's calculations.
Notes: Output per worker: FAO gross output index divided by number of persons working in agriculture. Output per hectare: FAO gross output index divided by total arable land and permanent pasture. Grain yield: Global production of maize, rice and wheat divided by area harvested of these crops. Total agricultural output is unfiltered and land input is not adjusted for quality.

by adding up output and input quantities to the global level and then constructing a new set of cost shares for aggregating inputs. The cost shares are the weighted average of each country's cost share (weighted by the country's global share in total cost or revenue). The agricultural output, input, and TFP growth estimates in Table 4.6 are derived using "raw" data—without the agricultural land quality adjustment or the output series filtered to reduce annual deviations from trends. Thus, these estimates are more easily comparable with other studies. I also show the average growth rates for output per worker, output per unit of agricultural land, and the average rate of yield increase in cereal grains (corn, rice, and wheat). The estimates show that global agricultural output grew at 2.8% per year in the 1960s and then maintained a fairly steady growth rate of slightly over 2% per year each decade since 1970. Over time, an increasing share of output growth was due to improvements in TFP rather than input accumulation. Input growth slowed significantly, from over 2.3% per year in the 1960s to only 0.74% per year during 2000-07 (and even lower in the 1990s when agricultural severely contracted in the transition economies of the former Soviet Union and Eastern Europe). Improvements in TFP kept global output growth steady as the rate of input accumulation fell.

The partial productivity indexes in Table 4.6 show continued growth over time but mixed trends in the rates of growth. Average output per worker rose by 1.25% per year and output per hectare by just over 2% per year over the entire 1961-2007 period. Note that growth in 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 contribute to growth of the partial productivity indicators but are removed from growth in TFP. While there is no clear evidence of a productivity slowdown in either of these indicators, and especially not since 1980, there is a clear decline in the rate of increase in cereal yield, as has been noted by others (see Chapter 3 in this volume). What the evidence in Table 4.6 suggests is that the decline in growth in cereal yields has been offset by productivity improvements elsewhere—in other crops and in livestock—so that productivity growth in the total agricultural economy has not suffered overall.

Figure 4.2 plots the sources of agricultural growth by decade, showing the contribution of TFP and each of the five input categories (land, labor, livestock

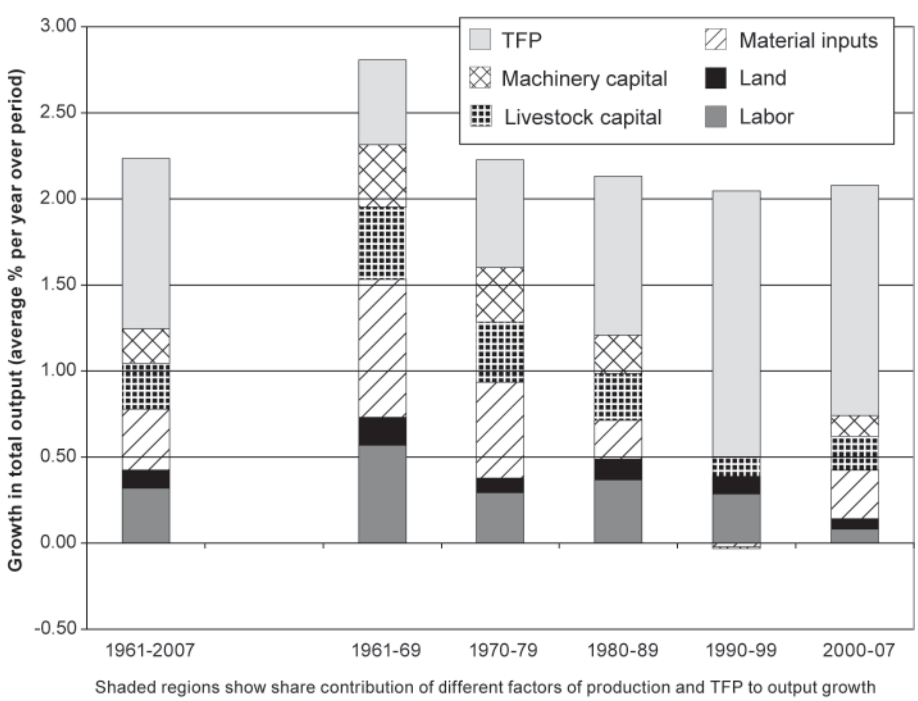

Figure 4.2. Sources of growth in global agriculture

Source: Author’s estimates.

capital, machinery capital, and material inputs) by decade. In this figure, land is quality adjusted and the output trend has been filtered (but the filtering has a negligible effect on average global growth rates). Growth in material inputs, especially in 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 long-run pattern shows that growth in agricultural production inputs gradually slowed, however, and the rate of increase in TFP accelerated to maintain real output growth at about 2% per annum. The exceptionally low rate of capital formation in global agriculture during the 1990s was due primarily to the rapid withdrawal of resources from agriculture in the countries of the former Soviet block. But many of the inputs used in these countries were apparently not efficiently applied, as their withdrawal significantly increased the average productivity of resources remaining in agriculture, evidenced by the high TFP growth rate in this decade. By 2000 agricultural resources in this region had stabilized and there was a recovery in the rate of global input growth compared with the 1990s.

The estimates of global agricultural output and TFP growth are disaggregated among regions and sub-regions in Table 4.7 (see Table 4.4 for the list of countries assigned to each region).[3] The regional results reveal that the global trend is hardly uniform, with three general patterns evident.

1. In developed countries, resources were being withdrawn from agriculture at an increasing rate; TFP continued to rise but the rate of growth in 2000-07 was under 0.9% per year, the slowest of any decade since 1961.
2. In developing regions, productivity growth accelerated in the 1980s and the decades following. Input growth steadily slowed but was still positive. Two large developing countries in particular, China and Brazil, have sustained exceptionally high TFP growth rates since the 1980s. Several other developing regions also registered robust TFP growth. The major exceptions were the developing countries of Sub-Saharan Africa, West Asia, Oceania, and the Caribbean.

[3]Annual indexes of TFP growth were estimated for each country for the entire 1961-2007 period (except for countries that made up the former Soviet Union, for which TFP indexes were estimated only for 1965-2007). Due to space limitations, Table 4.6 only reports averages by decade by region. Note that the growth rate in inputs can be derived simply by taking the difference between the output and TFP growth rates. Country-specific results are available from the author upon request.

Table 4.7. Agricultural output and productivity growth for global regions by decade

	Agricultural Output Growth						Agricultural TFP Growth					
Agricultural Growth	**61-69**	**70-79**	**80-89**	**90-99**	**00-07**	**61-07**	**61-69**	**70-79**	**80-89**	**90-99**	**00-07**	**61-07**
	(average annual % over period)											
All Developing Countries	3.16	2.82	3.47	3.65	2.99	3.23	0.18	0.54	1.66	2.30	1.98	1.35
Sub-Saharan Africa	3.06	1.32	2.63	3.21	2.81	2.58	0.36	-0.07	0.57	1.17	1.08	0.62
Nigeria	3.42	-0.89	5.07	5.36	3.26	3.24	-1.04	-2.21	1.80	3.78	2.51	0.99
Western (except Nigeria)	3.11	2.00	3.21	4.16	2.45	3.00	-0.08	-0.62	1.43	1.36	0.40	0.53
Sahel	1.84	1.03	2.47	3.34	3.09	2.35	-0.71	-0.65	0.76	0.16	0.68	0.05
Central	2.50	1.95	2.47	0.68	0.71	1.67	-0.65	-0.69	0.28	-0.56	0.04	-0.32
Eastern	4.00	2.42	2.43	1.54	2.94	2.60	0.93	0.38	0.20	-0.22	1.34	0.47
Horn	2.52	2.02	0.80	3.21	3.53	2.36	0.06	0.49	-1.08	0.68	1.77	0.34
Southern	3.12	1.20	1.22	2.16	2.09	1.90	0.65	-0.28	-0.23	1.11	0.81	0.38
Latin America & Caribbean	3.11	3.07	2.39	2.92	3.23	2.92	0.29	0.70	1.20	2.54	2.60	1.47
NE S. America (mainly Brazil)	3.56	3.82	3.70	3.31	4.05	3.68	-0.52	-0.76	3.08	3.81	3.63	1.87
Andean countries	3.25	2.85	2.37	3.10	2.25	2.76	1.45	0.59	1.01	2.73	1.74	1.49
Southern Cone	1.86	2.17	1.20	3.04	3.14	2.26	0.36	1.73	0.03	2.15	2.03	1.27
Caribbean	1.54	1.76	1.00	-1.31	0.50	0.67	-1.73	2.38	-0.63	-2.42	0.08	-0.43
Central America	4.84	3.57	1.70	2.76	2.61	3.04	2.41	1.76	0.20	2.26	2.62	1.79
Asia (except West Asia)	3.24	2.90	3.75	3.82	2.92	3.35	-0.02	0.63	1.95	2.60	2.37	1.53
NE Asia (mainly China)	4.72	3.11	4.55	5.04	3.04	4.11	-0.12	0.30	2.77	4.08	2.83	2.03
Southeast Asia	2.66	3.68	3.60	3.15	4.04	3.43	0.68	2.26	0.98	1.78	2.59	1.66
South Asia	1.92	2.55	3.40	2.94	2.66	2.73	0.07	0.64	1.98	1.60	1.70	1.23

Table 4.7. Continued

Agricultural Growth	Agricultural Output Growth 61-69	70-79	80-89	90-99	00-07	61-07	Agricultural TFP Growth 61-69	70-79	80-89	90-99	00-07	61-07
	(average annual % over period)											
West Asia & North Africa	3.00	2.96	3.44	2.83	2.06	2.89	0.57	0.43	1.80	1.69	1.29	1.17
North Africa	2.82	1.78	3.79	3.52	2.80	2.95	1.06	0.00	2.82	2.25	2.04	1.64
West Asia	3.08	3.45	3.30	2.54	1.72	2.85	-0.10	0.61	1.33	1.46	0.95	0.89
Oceania	2.54	2.27	1.71	1.84	1.40	1.95	-0.20	0.07	-0.11	0.63	0.43	0.17
All Developed Countries	2.08	1.86	0.88	1.16	0.17	1.24	1.21	1.52	1.47	2.13	0.86	1.48
United States & Canada	2.05	2.17	0.73	2.04	1.04	1.61	0.86	1.37	1.35	2.26	0.33	1.29
Europe (except FSU)	2.00	1.63	0.76	-0.12	-0.67	0.72	1.17	1.31	1.22	1.63	0.59	1.21
Europe, Northwest	1.57	1.35	0.94	0.20	-0.83	0.67	1.56	1.46	1.91	2.03	0.82	1.59
Europe, Southern	2.24	1.92	0.93	0.95	-0.19	1.18	0.84	1.19	0.97	1.74	0.91	1.15
Australia & New Zealand	3.09	1.75	1.27	1.31	-0.98	1.31	0.93	1.29	1.26	0.53	-0.53	0.74
Asia, developed (Japan, S. Korea, Taiwan, Sing.)	3.40	2.10	1.09	0.15	-0.54	1.22	-7.47	-0.86	0.39	1.59	1.80	-0.74
South Africa	3.02	2.55	0.98	1.12	1.46	1.79	0.50	1.53	1.80	2.75	3.09	1.95
Transition Countries	3.55	1.52	0.75	-3.72	1.40	0.55	0.67	-0.26	0.25	0.73	1.92	0.61
Eastern Europe	2.69	1.91	0.26	-2.03	-0.89	0.34	0.63	0.38	0.60	1.92	-0.12	0.72
Former Soviet Union	3.97	1.32	0.98	-4.61	2.60	0.64	0.73	-0.58	0.20	0.18	3.28	0.65
Baltic	3.78	1.20	1.30	-6.09	0.63	-0.37	1.96	-0.79	0.51	0.23	2.28	0.61
Central Asia & Caucasus	3.25	4.73	1.24	0.59	4.07	2.65	-0.56	1.85	-1.72	3.51	2.47	1.28
Eastern Europe	3.27	1.28	1.10	-4.66	2.36	0.22	1.23	-0.64	0.22	1.19	3.82	1.03

Source: Author's estimates.

3. The dissolution of the Soviet Union in 1991 imparted a major shock to agriculture in the countries of the former Soviet block. In the 1990s, agricultural resources sharply contracted and output fell significantly. However, by 2000, agricultural resources had stabilized and growth resumed, led entirely by productivity gains in the sector.

The strong and sustained productivity growth described here for a number of important developing countries, such as Brazil and China, is broadly consistent with results from other studies. Brazil is reaping the benefits from a strong agricultural research system and, since the mid-1990s, macroeconomic stability (Avila 2007). Using the Tornqvist-Theil index method, Gasquez, Bastos, and Bacchi (2008) estimated average annual agricultural TFP growth in Brazil to have averaged 3.26% over 1975-2008, even higher than my estimate of 2.80%, and both studies show an acceleration of TFP growth over time. China has had success since 1978 with both institutional reform and technological change (Rozelle and Swinnen 2004). Fan and Zhang (2002) estimated average annual Tornqvist-Theil TFP growth for Chinese agriculture at 2.6% during 1961-1997 with relatively slow growth until 1980, after which TFP rapidly accelerated. The present study also shows an accelerating pace to TFP growth in China, although at a lower average rate. My lower estimates of TFP growth could reflect an "index number bias" from the use of fixed factor and revenue shares in countries undergoing rapid structural and technological change.

A fair number of mid-size countries also recorded respectable levels of agricultural productivity growth, according to my estimates. Peru, Malaysia, Chile, South Africa, Iran, Mexico, Vietnam, Russia, Kazakhstan, and Uzbekistan all achieved average agricultural TFP growth rates of at least 2.5% per year during 1990-2007. However, with few exceptions, developing countries in Sub-Saharan Africa,[4] West Asia, the Caribbean, and Oceania continued to rely on resource-led agricultural growth rather than productivity, and as a consequence their agricultural sectors have performed poorly. Using the TFP estimates reported here, Evenson and Fuglie (2010) found TFP performance in developing-country agriculture to be strongly correlated with national investments in "technology capital," which they defined by indicators of a country's ability to develop and

[4]The estimates in Table 4.6 suggest Nigeria in Sub-Saharan Africa is also a leader in agricultural productivity growth, achieving average TFP growth over 2.5% since 1990. However, my recent assessment (Fuglie 2009) of agricultural productivity performance in this region casts doubt on this finding for Nigeria and uncovers serious data discrepancies.

extend improved agricultural technology to farmers. Countries that had failed to establish adequate agricultural research and extension institutions and extend basic education to rural areas were stuck in low-productive agriculture and were falling further behind the rest of the world.

4. CONCLUSION

Contrary to some other authors, I find no evidence of a general slowdown in sector-wide agricultural productivity, at least through 2007. If anything, the growth rate in agricultural TFP accelerated in recent decades, in no small part because of rapid productivity gains in several developing countries, led by Brazil and China, and more recently to a recovery of agricultural growth in the countries of the former Soviet bloc. 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 slightly more than 2% per year since the 1970s. This finding has important implications for the appropriate supply-side policy response to the recent rise in real agricultural prices.

One implication is that we should be optimistic 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 in this chapter is a slowdown in the rate of growth in agricultural capital formation. This is at least in part a consequence of a long period of unfavorable prices facing producers, who 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 block that precipitated a rapid exit of resources from agriculture in the 1990s. The incentives afforded by the current high commodity prices and a resumption of agricultural growth in the former Soviet countries 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.

Despite this generally optimistic conclusion, it is also clear that agricultural productivity growth has been very uneven. The evidence in this chapter suggests TFP growth may in fact be slowing in developed countries while accelerating in developing countries. This is in marked contrast to the early findings of Hayami and Ruttan (1985) and Craig, Pardey, and Roseboom (1997), which found developing countries to be falling further behind developed countries in agricultural land and labor productivity. Nonetheless, it remains true that many developing countries have not been able to achieve or sustain productivity growth in agriculture and as a consequence suffer from low levels of rural welfare and food security. This has not contributed to a *slowdown* in global TFP growth of the sector 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 many countries in West Asia, the Caribbean, and Oceania as well as some others.

There is also 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 land yield trends since labor and capital inputs tend to be shared across multiple commodities in the production process. Thus, the slowing growth in cereal grain yield that was identified in the *World Bank Development Report 2008* (World Bank 2007) does raise concerns that there is underinvestment (or low returns) to research directed at these commodities. But even here the picture is uneven, as 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 agricultur al 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.

REFERENCES

Avila, A.F.D. 2007. "Agricultural Productivity and Sources of Growth in Latin America." Paper prepared for an ERS Workshop on Trends & Forces in International Agricultural Productivity Growth, Economic Research Service, Washington, DC, March 15.

Avila, A.F.D., and R.E. Evenson. 1995. "Total Factor Productivity Growth in Brazilian Agriculture and the Role of Agricultural Research." *Anais do XXXIII Congresso Brasileiro de Economia e Sociologia Rural*, Vol. 1: Curitiba, Brazil, pp. 631-657.

———. 2004. "Total Factor Productivity Growth in Agriculture: The Role of Technology Capital." Mimeo., Yale Economic Growth Center, New Haven, CT.

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

Ball, V.E., J. Butault, C. Mesonada, and R. Mora. Forthcoming. "Agricultural Competitiveness." Chapter in *Economic Implications of Public Support for Agriculture: An International Perspective,* V.E. Ball, R. Fanfani, and L. Gutierrez, eds. New York: Springer.

Chambers, R. 1988. *Applied Production Analysis: A Dual Approach.* Cambridge: Cambridge University Press.

CISSTAT. CIS CD-ROM. Interstate Statistical Committee of the Commonwealth of Independent States. http://www.euros.ch/cistop.htm.

Coelli, T.J., and D.S.P. Rao. 2005. "Total Factor Productivity Growth in Agriculture: A Malmquist Index Analysis of 93 Countries, 1980-2000." *Agricultural Economics* 32: 115-134.

Council of Agriculture. Executive Yuan, R.O.C. "Statistic." Web site. http://eng.coa.gov.tw/list.php?catid=8821 (accessed December 2008.).

Craig, B.J., P.G. Pardey, and J. Roseboom. 1997. "International Productivity Patterns: Accounting for Input Quality, Infrastructure, and Research. *American Journal of Agricultural Economics* 79(4): 1064-1076.

Cungo, A., and J.F.M. Swinnen. 2003. "Transition and Total Factor Productivity in Agriculture, 1992-1999." Working Paper 2003/2, Research Group on Food Policy, Transition & Development, Katholieke Universiteit Leuven.

ERS (Economic Research Service). 2009a. Agricultural Productivity in the United States, Agricultural Research and Productivity Briefing Room, Economic Research Service, Washington, DC. http://www.ers.usda.gov/Data/AgProductivity/.

———. 2009b. China Agricultural and Economic Data, China Briefing Room, Economic Research Service, Washington, DC. http://www.ers.usda.gov/data/china/.

Eurostat. Database, Statistics, "Employment and Unemployment (LFS)." European Commission. http://epp.eurostat.ec.europa.eu/portal/page/portal/employment_unemployment_lfs/data/database (accessed October 2009).

Evenson, R.E., and K.O. Fuglie. 2010. "Technological Capital: The Price of Admission to the Growth Club." *Journal of Productivity Analysis* 33 (forthcoming).

Evenson, R.E., C. Pray, and M. Rosegrant. 1999. "Agricultural Research and Productivity Growth in India." Research Report Number 109, International Food Policy Research Institute, Washington, DC.

Fan, S., P. Hazell, and S. Thorat. 1999. "Linkages between Government Spending, Growth, and Poverty in Rural India." Research Report 110, International Food Policy Research Institute, Washington, DC.

Fan, S., and X. Zhang. 2002. "Production and Productivity Growth in Chinese Agriculture: New National and Regional Measures." *Economic Development and Cultural Change* 50(4): 819-838.

FAOSTAT Database. United Nations Food and Agriculture Organization, Rome. http://faostat.fao.org/ (accessed July 2008).

Fernandez-Cornejo, J., and C.R. Shumway. 1997. "Research and Productivity in Mexican Agriculture." *American Journal of Agricultural Economics* 79(August): 738-753.

Fuglie, K.O. 2004. "Productivity Growth in Indonesian Agriculture, 1961-2000." *Bulletin of Indonesia Economic Studies* 40(2): 209-225.

———. 2009. "Agricultural Productivity in Sub-Saharan Africa." Paper presented at the Conference on the Food and Financial Crises and Their Impacts on the Achievement of Millennium Development Goals in Africa, Cornell University, Ithaca, New York, May 1-2.

———. 2010. "Sources of Productivity Growth in Indonesian Agriculture." *Journal of Productivity Analysis* 33 (forthcoming).

Fuglie, K.O., N. Ballenger, K. Day, C. Klotz, M. Ollinger, J. Reilly, U. Vasavada, and J. Yee. 1996. "Agricultural Research and Development: Public and Private Investments under Alternative Markets and Institutions." Agricultural Economic Report Number 735, Economic Research Service, Washington, DC, May.

Gasquez, J.G., E.T. Bastos, and M.R.P. Bacchi. 2008. "Productividade e fontes de crescimento da agricultura Brasileira" [The rate of productivity growth in Brazilian agriculture]. Mimeo., Applied Economic Research Institute (IPEA), Government of Brazil, Brasilia.

Hertford, R., 1971. "Sources of Change in Mexican Agricultural Production, 1940-65." Foreign Agricultural Economic Report No. 73, Economic Research Service, U.S. Department of Agriculture, Washington, DC.

Hayami, Y., and V.W. Ruttan. 1985. *Agricultural Development: An International Perspective.* Baltimore MD: Johns Hopkins University Press.

International Fertilizer Association. "Statistics, IFADATA." Web site. http://www.fertilizer.org/ifa/ifadata/search (accessed August 2009).

IPGE (Instituto Brasileiro de Geografia e Estatística). 2008. Ministry of Planning, Brasilia, Brazil. http://www.ibge.gov.br/ (accessed July 2008).

LABORSTA. Database, Bureau of Statistics, International Labor Organization, Geneva, Switzerland. Available at http://laborsta.ilo.org/ (accessed October 2009).

Lerman, Z., Y. Kislev, D. Biton, and A. Kriss. 2003. "Agricultural Output and Productivity in the Former Soviet Republics." *Economic Development and Cultural Change* 51(July): 999-1018.

Liebenberg, F., P.G. Pardey, and M. Kahn. 2010. "South African Agricultural Research and Development: A Century of Change." Staff Paper P 10-1, Department of Applied Economics, University of Minnesota, January.

Ludena, C.E., T.W. Hertel, P.V. Preckel, K. Foster, and A. Nin. 2007. "Productivity Growth and Convergence in Crop, Ruminant, and Nonruminant Production: Measurement and Forecasts." *Agricultural Economics* 37: 1-17.

Lusigi, A., and C. Thirtle. 1997. "Total Factor Productivity and the Effects of R&D in African Agriculture." *Journal of International Development* 9(4): 529-538.

National Bureau of Statistics of China. 2006. National Bureau of Statistics of China, Beijing, China. http://www.stats.gov.cn/engish/statisticaldata/yearlydata/.

Peterson, W. 1987. "International Land Quality Indexes." Staff Paper P87-10, Department of Applied Economics, University of Minnesota, April.

Rao, D.S.P. 1993. "Intercountry Comparisons of Agricultural Output and Productivity." FAO Economic and Social Development Paper, United Nations Food and Agriculture Organization, Rome.

Ravn, M.O., and H. Uhlig. 2002. "On Adjusting the Hodrick-Prescott Filter for the Frequency of Observations." *Review of Economics and Statistics* 84(2): 371-376.

Rozelle, S., and J.F.M. Swinnen. 2004. "Success and Failure of Reform: Insights from the Transition of Agriculture." *Journal of Economic Literature* 42(June): 404-456.

Shend, J.Y. 1993. "Agricultural Statistics of the Former USSR Republics and the Baltic States." Statistical Bulletin No. 863, Economic Research Service, U.S. Department of Agriculture, Washington, DC.

Swinnen, J.F.M., L. Dries, and K. Macours. 2005. "Transition and Agricultural Labor." *Agricultural Economics* 32: 15-34.

Thirtle, C., and P. Bottomley. 1992. "Total Factor Productivity in UK Agriculture, 1967-90." *Journal of Agricultural Economics* 43: 381-400.

Thirtle, C., H. Sartorius von Bach, and J. van Zyl. 1993. "Total Factor Productivity in South African Agriculture, 1947–91." *Development Southern Africa* 10(3): 301-317.

Van der Meer, C.L.J., and S. Yamada. 1990. *Japanese Agriculture: A Comparative Economic Analysis*. London and New York: Routledge.

Wiebe, K., M.J. Soule, C. Narrod, and V.E. Breneman. 2003. "Resource Quality and Agricultural Productivity: A Multi-Country Comparison." In *Land Quality, Agricultural Productivity and Food Security: Biophysical Processes and Economic Choices at Local, Regional and Global Levels*, K. Wiebe, ed. Northampton, MA: Edward Elgar, pp. 147-165.

World Bank. 2007. *World Bank Development Report 2008*. Washington, DC: Author.

Part 2

Country-Specific Evidence