CHAPTER 15

Shifting Patterns of Global Agricultural Productivity: Synthesis and Conclusion

Julian M. Alston, Bruce A. Babcock, and Philip G. Pardey

1. INTRODUCTION

The food commodity price spike of 2008 drew the attention of various commentators and policymakers once more to some old questions about the long-term capacity of the world to feed itself. Prior to that price spike, some economists had already begun asking questions about shifting agricultural productivity patterns, and some evidence had begun to emerge suggesting that agricultural productivity growth rates might have slowed.[1] The food price spike gave force to the existing interest in whether productivity growth rates had slowed, to what extent, and where. The future shape of the world food equation is sufficient reason to be interested in agricultural productivity paths; comparative advantage, or competitiveness, is another

Julian Alston is a professor in the Department of Agricultural and Resource Economics, University of California, Davis, and associate director, Science and Technology, at the University of California Agricultural Issues Center. Bruce Babcock is a professor of economics and director of the Center for Agricultural and Rural Development at Iowa State University. Philip Pardey is a professor in the Department of Applied Economics, University of Minnesota, and director of the International Science and Technology Practice and Policy (InSTePP) center at the University of Minnesota.

[1]For instance, Thirtle et al. (2004) found strong evidence of a significant slowdown in UK agricultural productivity growth. Motivated by emerging indications of a U.S. slowdown (see, e.g., some initial perspectives on these trends in Alston and Pardey 2007) and speculation that it might be a more widespread phenomenon, an organized symposium on the issue was held at the International Association of Agricultural Economists conference in Australia in August 2006. A mixture of views were expressed. Discerning a structural shift in productivity trends is difficult. For example, as Nordhaus (2004) described, there was (and likely remains) no unanimity of views among economists about the existence and magnitude (let alone sources) of an economy-wide productivity slowdown in the United States in the 1970s.

reason. In particular, the future competitive position of the United States may be threatened if, for instance, the growth rate of U.S. agricultural productivity falls far behind the corresponding growth rates of productivity in China and Latin America, as some of the numbers reported here would suggest may be happening.

This book does not provide forecasts about the future path of agricultural productivity. However, a quantitative understanding of agricultural productivity movements over the recent past and in the longer run is a useful first step toward gaining a sense of what we can expect in the years ahead. This book compiles and evaluates readily available existing information on agricultural productivity patterns around the world. Based on this compilation we make an assessment and synthesis of what is already known (or can be taken from work that has already been done) and thereby draw inferences about what has been happening in global and national agricultural productivity.

This book comprises a total of 15 chapters. It begins with a short introduction (in Chapter 1). Part 1 of the book, "International Evidence and Interpretation," comprises three chapters (Chapters 2, 3, and 4), each of which provides a different global perspective on elements of agricultural productivity patterns. Part 2 presents "Country-Specific Evidence" in the form of 10 chapters (Chapters 5-14), each of which represents a single country, or grouping of countries in the case of Chapter 5 (Australia and New Zealand) and Chapter 10 (Former Soviet Union and Eastern Europe). The presentation of information varies significantly among the chapters, reflecting differences in availability of data and other resources among the countries and regions covered, and differences in purposes of and methods used in the foundation studies from which the chapters were drawn. This final chapter is a summary and conclusion. The purpose of this chapter is to summarize, synthesize, and attempt to make sense of the diverse and sometimes contradictory information contained in the previous 14 chapters.

2. METHODS OF MEASUREMENT AND MEASURES OF PRODUCTIVITY PATTERNS

Before turning to those specifics, in this section we discuss measures and methods used in studies of this nature, aiming to provide a framework to be used in interpreting the work presented in the individual chapters. We then present a detailed summary and synthesis of the key findings.

2.1. Primal Measures of Productivity and Productivity Growth

Much has been written by economists on how to measure productivity and how to interpret the measures (e.g., Jorgenson and Griliches 1967; Alston, Norton, and Pardey 1998; Morrison-Paul 1999). Different concepts and corresponding measures of productivity may be appropriate for different purposes, though they all express some measure of output relative to some measure of input.

The simplest measure of all is a measure of output of a single commodity per unit of a single input, such as yield in tons per hectare of wheat per year. This seems straightforward. However, even such a seemingly simple and intuitive measure is prone to conceptual and measurement problems. For instance, land quality varies such that individual hectares are quite unequal in their productive capacity. Do we use planted or harvested area and measure seasonal or annual acreages when forming measures of yields? Should the units of land be adjusted for quality to make the individual hectares more nearly comparable? If not, how should we interpret changes in observed yields that may reflect changes in the intensity of use or average quality of the land input? Similarly, on the output side, wheat quality varies significantly, depending on protein content and other attributes that are not independent of the physical yield—in particular, higher yield tends to be associated with lower quality (James 2000; Alston and James 2002). What should be done about changes in output quality? If nothing is done to correct for variations in the quality mix over space and time, how should we interpret the measures? Further complications arise from the implicit aggregation over time. For instance, in some cases multiple crops are grown on the same fields within one year; in other places a crop is grown in a multiyear rotation with other crops or with fallow years. How should the measures of yield per hectare per year be adjusted to allow for these characteristics of the production process so as to make the measures comparable over space and time?

Problems often arise from difficulties in matching the timing, location, form, and coverage of inputs to the corresponding outputs, and prices to quantities. For example, sub-national (state or provincial) quantities may be reported, but often only national-level prices are available for use as weights to aggregate these quantities. Sometimes agricultural production aggregates span crop, livestock, and forestry (and possibly aquaculture) products, whereas the available land, labor, or other inputs are specific to, say, crops and livestock only, causing a mismatch between inputs and outputs. Absent or missing input and output data are prevalent and persistent problems in productivity studies, occasioning the use of a myriad of ad hoc data interpolation techniques with direct consequences for the measurement and interpretation of the resulting agricultural production aggregates.

Individual grain yield is an example of a *partial factor productivity* (PFP) measure. It is "partial" in the sense that it only accounts for changes in the amount of land used in production. It does not account for changes in the quantities of other inputs—such as labor, capital, fertilizer, rainfall, or irrigation—that also affect production. By the same token, grain yield per hectare of a particular crop also does not account for changes in other outputs that might be associated with the output in question, such as crop biomass or other by-products. Thus yield and other partial measures can be seen as partial with respect to their treatment of outputs as well as inputs.

At the opposite end of the spectrum are measures of *total factor productivity* (TFP), the aggregate quantum of all outputs divided by the aggregate quantum of all of the inputs used to produce those outputs. TFP is a theoretical concept. All real-world measures omit at least some of the relevant outputs and some of the relevant inputs, and therefore it is more accurate to refer to the real-world measures as *multifactor productivity* (MFP) measures. Particular MFP measures differ in the extent to which they fall short of the counterpart ideal TFP measure because of methodological differences as well as differences in the consequences of incomplete coverage of the inputs and outputs. Some of the methodological or measurement issues fit under the rubric of "index number problems." How do we add up different outputs—not just apples and oranges but also livestock products such as milk and various meats, and a range of grains, oilseeds, fruits, nuts, vegetables, and other crops—to create a meaningful measure of the aggregate (agricultural) output quantity? Likewise, how should inputs be added up to aggregate across various types and qualities of land, and heterogeneous labor; across capital services from buildings, various types of machinery, and livestock; as well as a range of purchased inputs including agricultural chemicals?

Economists have developed a body of theory and a set of approaches that use prices (or value shares) to weight quantities to obtain so-called superlative indexes of aggregate quantities. Likewise, quantities (or value shares) are used as weights to obtain corresponding superlative indexes of prices. Divisia indexes (or discrete time approximations to Divisia indexes) of quantities use varying contemporary prices as weights and thereby avoid the index-number biases that are entailed in using fixed (initial base-period or ending-period) prices as weights.[2]

[2]Fixed-weight quantity indexes using initial base-period prices as weights are commonly called Laspeyres indexes, whereas indexes using final-year prices as weights are called Paasche indexes.

The quality of these approximations depends on the use of the appropriate price weights applied to fully disaggregated quantities. In particular, when the prices used by farmers to make production decisions vary significantly across locations for a given quality (e.g., states within the United States or countries within a region of the world) as well as across qualities in a particular location, it is desirable to use location-specific and quality-specific prices. Many studies do not have access to spatially disaggregated prices and use national or regional prices as proxies. The extent of index number bias from this source will depend on the extent to which movements in the proxy prices represent movements in the disaggregated prices.

Similar concerns arise with aggregation over qualities or types of goods. In most cases, when Divisia approximations are used they are applied to pre-aggregated quantity data for intermediate categories of goods, for which the corresponding prices are average unit values rather than appropriate price indexes. In many cases the available quantity data were obtained using methods that are not consistent with index number theory and the measures therefore suffer from some unknown degree of index number bias. A failure to adjust for quality or other compositional differences within an aggregate (such as different ages, sizes, or horsepower categories of tractors and other machinery used on farms; different qualities of agricultural land; or different age, education, and health status of farm labor) can be seen as a type of pre-aggregation that may lead to biases that will be worse if fixed weight indexes are used, especially if quality or compositional changes within categories have been important. Such distortions arise with indexes of PFP, MFP, and TFP whenever the quantities in the numerator or the denominator of the productivity measure involve aggregation over heterogeneous elements.

In the present context, as in many others, we are most interested in TFP since it is an encompassing measure that represents the full quantity of resources used to produce the total quantity of output produced. How well does an MFP or PFP measure approximate TFP? The main ideas can be illustrated with some simple mathematics. Let us define total output, Q, as the sum of the quantities of outputs *included* in MFP, Q_i, and the outputs *excluded* from MFP, Q_e (where $Q_e / Q = q_e$), and total input X as the sum of the quantities of *included* inputs, X_i, and *excluded* inputs, X_e (where $X_e / X = x_e$), such that the measures of TFP and MFP are

$$MFP = \frac{Q_i}{X_i}, \tag{1}$$

$$TFP = \frac{Q}{X} = \frac{Q_i + Q_e}{X_i + X_e}. \tag{2}$$

Taking logarithmic differentials of equations (1) and (2) gives measures of growth rates of MFP and TFP. Taking the difference between the logarithmic differentials gives an equation for the difference between growth in TFP and growth in MFP as follows:

$$\begin{aligned} d\ln TFP - d\ln MFP &= d\ln(Q_i + Q_e) - d\ln(X_i + X_e) - d\ln(Q_i) + d\ln(X_i) \\ &= q_e(d\ln Q_e - d\ln Q_i) - x_e(d\ln X_e - d\ln X_i). \end{aligned} \tag{3}$$

Thus the discrepancy depends on the relative importance of the excluded quantities of outputs and inputs (q_e and x_e), and on the differences in the growth rates between the included and excluded quantities of outputs and between the included and excluded quantities of inputs.

Importantly, if the excluded quantities of outputs and inputs are growing at the same rates as their included counterparts, the MFP measure grows at the same rate as the TFP measure. If the growth rates are different, however, the MFP growth rate will be different, with the difference increasing with the relative importance of the excluded outputs and inputs unless by chance the distortions in the outputs and inputs offset one another. For instance, in the United States, the purchased inputs category has been a relatively rapidly growing category of inputs. All other categories have been shrinking, especially operator labor. The greenhouse and nursery products category has been by far the fastest growing category of outputs (see Alston et al. 2010 for details). If we were to exclude purchased inputs, we would seriously understate growth in inputs, and therefore overstate growth in productivity. Conversely, if we were to exclude greenhouse and nursery products we would understate output growth and understate productivity growth. If we were to exclude both purchased inputs and nursery and greenhouse products, the net effect may be to increase or decrease the measured productivity growth depending on the relative importance of the two biases.

Of course, all such measures are only as good as the data used to create them. In many cases the data on inputs and outputs are sadly incomplete (in terms of their coverage), inconsistent (their coverage or definitions may change over space or time or both), inaccurate (many countries do not have the wherewithal to maintain reliable data collection systems), or otherwise inadequate. For example, if data exist at all, counts of tractors may be used as a proxy measure of total machinery services without any regard for changes in the relative importance of tractors vis-à-vis other forms of capital used in agriculture, quality changes in tractors, or variable utilization rates. The extent of these problems varies among studies, among countries, and over time. A primary concern is that in some cases the measures of quantities, especially for capital inputs, are seriously flawed.[3] The omission of key categories of rapidly growing inputs (in many instances, inputs that are increasingly purchased from off-farm sources, including management and other production-related information services) is also likely to have contributed to significantly distorted measures of TFP in some instances.

Most of the available measures of agricultural productivity growth relate to aggregate agriculture for a particular nation or region. Some studies have reported disaggregated measures for parts of agriculture, and the disaggregation can entail some additional measurement pitfalls. For instance, Huffman and Evenson (1992, 1993) reported U.S. state-level productivity for livestock and crops, but to do so they had to allocate aggregate inputs between crops and livestock, with little basis for doing so because the input data are reported on a geographic basis, not specific to individual outputs. Veeman and Gray (this volume, Chapter 6) applied a similar partitioning of inputs to infer productivity measures for crops and livestock production. It is appropriate to use such estimates carefully, given how they are derived. In contrast, Mullen (this volume, Chapter 5) reported estimates for a subsector of Australian agriculture ("broadacre" agriculture) that were based on a specific survey of farms in that subsector conducted by the Australian Bureau of Agricultural and Resource Economics (ABARE), as well as the estimates for aggregate agriculture developed by the Australian Bureau of Statistics.

A small number of studies have computed measures for individual commodities. To make such estimates requires apportioning inputs—whether purchased inputs such as fertilizer or allocatable fixed factors such as farmers' time or machinery—among multiple outputs in a setting where multiple outputs are the norm at the level of the firm as well as the region or nation. This can be done by applying detailed surveys or making assumptions when using index number approaches. Alternatively, estimates can be obtained econometrically in a multi-out-

[3]In many studies, measures of labor use are equally flawed. Often only total counts of workers in farming or agriculture are available, rather than hours of labor used in agriculture differentiated into various age, education, and other (productivity related) cohorts, with potentially significant consequences for the measures of the use of labor in agricultural production.

put model of agricultural production. For instance, Jin, Huang, and Rozelle (this volume, Chapter 9) used data envelopment analysis methods to estimate commodity-specific productivity growth rates, and to partition commodity-specific productivity growth between gains in allocative efficiency and technological change.

2.2. Dual Measures of Productivity

The measures of agricultural productivity based on indexes of quantities of inputs and outputs are "primal" measures. Alternative measures, based on indexes of prices of inputs and outputs, are referred to as "dual" measures of productivity. Under certain conditions, the dual and primal measures coincide exactly. Why this is so can be demonstrated simply. Specifically, under constant returns to scale and all of the other conditions of perfect competition, total expenditure on all inputs will be equal to total revenue from the sale of all outputs. Defining the indexes of the price and quantity of output as P and Q, and the indexes of the price and quantity of input as W and X, this zero profit condition can be stated as follows:[4]

$$PQ = WX. \tag{4}$$

Dividing both sides of (4) by X times P yields the result that

$$\frac{Q}{X} = \frac{W}{P}. \tag{5}$$

Thus, the ratio of the price index for inputs to the price index for output (the inverse of what is sometimes referred to as the farmers' terms of trade) is exactly equal to the primal measure of MFP as defined in equation (1).[5]

Of course, given the lag relationships in agricultural production and the resulting uncertainty about quantities and prices, we do not expect the zero profit condition to hold exactly in observed, ex post data, even under competition. In addition, especially in the short run, the prices of inputs and outputs in particular locations and at particular times may be influenced by idiosyncratic influences, including storage and government policies. Even so, given that the assumptions of competition and constant returns to scale can be regarded as generally reasonable

[4]Here we assume that the price and quantity indexes for inputs and outputs satisfy the "weak factor reversal test," which holds for superlative indexes such as the Fisher Ideal and Tornqvist-Theil index but does not hold for fixed-weight indexes such as the Paasche or Laspeyres (e.g., see Diewert 1976).

[5]See also Hulten 1986 and Roeger 1995.

approximations for agriculture, equation (5) should tend to hold fairly strongly in the longer run. Consequently, as Alston, Beddow, and Pardey (2009a) observed, it is no coincidence that the rate of decline of farmers' terms of trade is often very similar to the rate of increase in MFP. Indeed, this is something that we should expect to find globally in the long term, albeit with significant departures in particular circumstances in the short term (for instance, during the period around the price spike of 2008). Hence, even if we cannot obtain good data on quantities of agricultural inputs and outputs for some countries, we might still be able to derive a reasonable assessment of the rate of agricultural productivity growth using corresponding data on prices of inputs and outputs.[6] Of course the quality of the dual index of MFP depends on the same kinds of factors that influence the quality of the primal measures, so we should use the dual measures with corresponding care. But at a minimum, data on trends in relative prices provide a check on the plausibility of primal measures in cases in which the underlying data may be incomplete or otherwise dubious.

2.3. Measuring and Testing for Structural Change in Productivity Growth

The interpretation of results from testing for structural change in productivity growth may depend on the methods used and details of the application, as discussed briefly by Alston et al. (this volume, Chapter 8). An important first step is to be clear about the concept of productivity growth: are we testing for constant linear growth, as in a constant annual increase of x bushels per acre, or constant proportional growth, as in a constant increase of yield by y% per year? A constant proportional growth rate requires an exponential productivity path. If productivity is growing linearly, then the proportional (or percentage) rate of growth will decline because the denominator is growing. In this book, as in most (policy) contexts, the issue is whether the *proportional* growth rate of productivity has declined in the more recent period.

One way to test for a structural change is to compute year-to-year proportional growth by taking first differences in the logarithms of the productivity indexes and then averaging these annual values. This can be done for various subperiods, and the results can be compared to check for changes between subperiods. The year-to-year growth rates in agriculture typically vary signifi-

[6]Of course, data on prices may be thin or nonexistent in some circumstances, especially for subsistence economies with fewer traded goods, precisely the circumstances in which quantities produced may also be hard to ascertain.

cantly, reflecting the fact that productivity indexes jump up and down from year to year as a result of weather and other random (or unmeasured) factors. Consequently, in this approach the measures of average annual productivity growth rates, and tests for changes between subperiods, can be sensitive to starting and ending points for subperiods. What we make of this sensitivity will depend in part on whether we think the year-to-year movements reflect actual variations in productivity, or whether they are interpreted as measurement error. If we think the year-to-year movements reflect meaningful variations in productivity, then no adjustments to the measures should be made. However, if we think the year-to-year movements substantially reflect measurement errors, or temporary random influences, then for some purposes we would prefer alternative measures of growth that are less heavily influenced by such movements.

The main alternative approach is to regress the natural logarithm of the measure of productivity against time. The slope coefficient from this regression is an estimate of the rate of productivity growth. These coefficients can be estimated for different subperiods and they can be tested for structural changes between subperiods. This approach is easy and convenient for hypothesis testing. Compared with the average of annual growth rates, the regression approach is less sensitive to starting and ending points of subperiods but more sensitive to other outliers in the sample. This method is also subject to bias from specification error, if the true path of productivity growth is not exponential, or from other failures of the linear regression model. Given their different weaknesses, we do not have a good a priori basis for strongly preferring either approach over the other. It may be desirable in practice to try both approaches and explore the sensitivity of findings to starting and ending points and extreme values.

A third alternative is to estimate productivity growth in the context of a model of production, as done by Jin, Huang, and Rozelle (this volume, Chapter 9). In this approach the risk is that specification errors in the model, or bias in the model estimates arising from problems with the data, could give rise to bias in the estimates of productivity growth and its partition between allocative efficiency and technological change. Such models often yield surprising results. When it is difficult to measure a particular parameter with confidence or precision, it is typically doubly difficult to measure changes in that parameter using the same approach. We suspect that the measures of changes in productivity growth rates derived from the application of index number approaches are likely to be less fragile than those from econometric models.

3. SUMMARY AND SYNTHESIS

In this section we summarize the key points, chapter by chapter, and interpret them drawing on the discussion of methods and measures in the previous section. Where appropriate we compare, contrast, and attempt to reconcile findings across chapters.

Chapter 2. Agriculture is an inherently spatial process, with yields and output being greatly influenced by local factors such as weather and climate, soils, and pest pressures. Agricultural production and productivity are also influenced by the joint decisions of what to produce, when, where, and how to produce it. Consequently, spatial variation in the location of production has important implications for how productivity metrics can and should be interpreted.[7] Such considerations apply with more force when we aggregate across larger and more diverse spaces, and across outputs, especially if the mix of outputs is changing over time and space. Hence, when we study changes over time in aggregate crop yields, other PFP measures, or MFP measures, it is important to pay attention to the role of changes in the location of production as a contributing factor.

In their analysis of "The Changing Landscape of Global Agriculture" in Chapter 2, Beddow, Pardey, Koo, and Wood present data on the shifting location of agricultural production both among and within countries and regions. The authors begin by presenting a broad assessment of changes in the global footprint of agriculture over the past three centuries, drawing on data developed by Ramankutty and Foley (1999) and Ramankutty et al. (2008). Next, they use the commodity- and country-specific data assembled by the Food and Agriculture Organization (FAO) and agroecologically specific data first assembled by You and Wood (2005) to undertake a crop-specific assessment of the changing landscape of production within and among countries over the period 1961-2007. They show that global agriculture is spatially mobile, both over the long run stretching back several centuries (and into prehistory) and during more recent decades. Further, both the location of cropped areas and the quantity of crop production vary among countries as well as across agroecological areas within countries. As

[7]Even within a country and for a given crop, the spatial location of production and the concomitant choice of production technology have important implications for yield. Consequently, to understand changes in national average yields we have to understand the spatial dynamics of production. For example, as demonstrated by Olmstead and Rhode (2002) in their study of U.S. wheat yields, the fact that yields did not decline over the period 1866 to 1939 (in fact they remained almost constant, growing by just 0.15% per year) was testament to substantial varietal innovation to adapt varieties to the much different agroecological conditions as the industry moved from the East Coast into the Midwest and the Dakotas. See also Beddow 2010.

the authors illustrate, these sizeable shifts in the spatial structure of agriculture add substantial complexity to understanding measured changes in agricultural productivity, particularly when the location of crop production shifts among agroecologies both within and among countries over time.

Chapter 3. Alston, Beddow, and Pardey present an analysis of "Global Patterns of Crop Yields and Other Partial Productivity Measures and Prices." The chapter begins with a review of trends in the U.S. prices of staple food and feed commodities (corn, rice, soybeans, and wheat). As well as representing a primary consequence from productivity growth, the long-term trends in deflated commodity prices can be interpreted as a rough dual index of productivity growth. Deflated prices of farm commodities trended down generally through most of the twentieth century, with substantial disruptions associated with the Great Depression of the 1930s, several major wars, and the global economic events of the early 1970s and the past few years. The rate of decline in commodity prices accelerated after World War II, especially after the price spike of the early 1970s, but slowed in the 1990s and into the twenty-first century, especially in the case of the food grains, wheat and rice, prior to the spike in 2008. This slowdown in the rate of decline of real commodity prices is consistent with a slowdown in the primal rate of productivity growth, measured in terms of output versus input quantities.

The authors present a range of partial productivity measures for a range of geopolitical aggregates as well as globally. These measures include yields for major crops as well as measures of aggregate agricultural output per unit of land or labor employed in production, taken from the FAO (FAOSTAT Database accessed in May and October 2008). Corn and wheat yields each grew by a factor of 2.6 from 1961 to 2007; over the same period, rice yields increased by a factor of 2.2. For all three crops, in both developed and developing countries, average annual rates of yield growth were much lower in 1990-2006 than in 1961-1990. However, the authors noted potential problems of interpretation given multiple cropping in some places, and the changing location of production, as discussed and documented by Beddow et al. (this volume, Chapter 2).

Moving beyond crop yields to more broadly construed productivity measures, global productivity trends show a 2.4-fold increase in aggregate output per harvested area since 1961 (equivalent to annual average growth of 2.0% per year) and a corresponding 1.7-fold increase (or growth of 1.2% per year) in aggregate output per agricultural worker. These productivity developments reflect a comparatively faster rate of growth in global agricultural output against relatively slower growth in the use of agricultural land and labor (0.3% and 1.1% per year, respectively). In parallel with the global crop yield evidence, the longer-run growth in land and labor productivity masks a widespread—albeit not universal—slowdown in the rate of growth of both productivity measures during 1990-2005 compared with the previous three decades. China and Latin America are significant exceptions, both having considerably higher growth rates of land and labor productivity since 1990. Worldwide, after 1990 the growth rate of land productivity slowed from 2.03% per year to 1.82% per year, whereas the growth rate of labor productivity increased from 1.12% per year for 1961-1990 to 1.36% per year for 1990-2005. These world totals are heavily influenced by the significant and exceptional case of China (see also Jin, Huang, and Rozelle, this volume, Chapter 9). Netting out China, global land and labor productivity growth has been slower since 1990 than during the prior three decades. The same period relativities prevail if the former Soviet Union (FSU) is also netted out, although the magnitude of the global productivity slowdown net of China and the FSU is less pronounced because both partial productivity measures for the FSU actually shrank after 1990 (see also Swinnen, Van Herck, and Vranken, this volume, Chapter 10).

In summary, Alston, Beddow, and Pardey find consistent evidence, using a range of measures, of an economically significant slowdown in agricultural productivity growth in most of the world since 1990. Important exceptions are China and Latin America. In the rest of the world—including both the world's richest countries and the world's poorest countries—the slowdown in agricultural productivity growth has been substantial and widespread. Like Alston, Beddow, and Pardey (2009b), the authors speculate that an earlier slowdown in agricultural research and development (R&D) spending growth might have contributed to the recent slowdown in productivity growth. They also argue that, regardless of the cause of the slowdown, a revitalized investment in agricultural R&D is justified.

Chapter 4. In his analysis of "Total Factor Productivity in the Global Agricultural Economy: Evidence from FAO Data," Fuglie reports an extensive set of estimates of productivity growth rates for countries, regions, and for the world as a whole. His measures include some of the same types of partial productivity measures as reported by Alston, Beddow, and Pardey (this volume, Chapter 3), as well as some TFP measures, of the types that some other chapters reported for particular countries. In contrast to Alston, Beddow, and Pardey, Fuglie rejects the hypothesis of a slowdown in global agricultural productivity growth. This difference in conclusions might reflect differences in interpretation of the same or similar evidence, as well as different evidence. And differences in the evidence might reflect differences in methods, measures, data used, or time periods covered. In seeking to reconcile these views, we first consider the nature and extent of the differences in findings between Alston, Beddow, and Pardey versus Fuglie and then we explore sources of differences.

The two studies concur generally with respect to crop yields: both find a substantial slowdown since 1990, especially for food grains and less so for corn, which, in the rich countries at least, has benefited from substantial and sustained research attention from private firms for many decades. With respect to other partial productivity measures for the world as a whole, both studies report a slowdown in growth of land productivity and an acceleration in labor productivity growth since 1990. The specific estimates differ because they use different measures and they apply to different time periods, but the essential finding is similar with respect to the partial productivity measures for the world as a whole. Both chapters also refer to the diversity of results among countries, and the differences between the chapters are probably more pronounced in particular instances.

Alston, Beddow, and Pardey emphasize the role of China in lifting the average measures for the world and developing countries as a group. When they exclude China, they find a slowdown in growth of both land and labor productivity for the rest of the world as a whole. Fuglie does not report a corresponding set of measures for the world excluding China. Both chapters report that, along with China, Latin America has done relatively well. Both chapters also point to the role of institutional change in China, contributing positively to recent productivity growth, and in the FSU, contributing to productivity declines during the transition period followed by an uneven pattern of recent recovery. Alston, Beddow, and Pardey raise the issue that productivity growth associated with institutional changes of this nature may be transient rather than enduring, such that one should not presume to extrapolate a recent surge in the rate of growth, associated with one-off institutional reforms, into the indefinite future.[8]

Even when the two chapters refer to the same concept applied to the same place (e.g., crop yields, land productivity, labor productivity) there will be differences in the measures associated with differences in time periods covered and

[8]China has followed these institutional reforms by ramping up its investments in agricultural R&D. But the impression is that a similar acceleration in growth-promoting R&D investments has not occurred in the FSU, or at least not to the same extent as observed for China.

differences in methods. Specifically, although the land and labor productivities reported in Chapters 3 and 4 are ostensibly similar in intent and construct, differences in the details may have empirical consequences. In forming the numerator for their partial productivity metrics, Alston, Beddow, and Pardey constructed their own measures of aggregate output using quantity data (spanning 185 crop and livestock commodities) downloaded from the FAO Web site in conjunction with FAO's 2000 centered international agricultural commodity prices. Fuglie directly employed the FAO gross production index, which uses 195 crop and livestock categories weighted by the same set of average agricultural prices. Both studies used FAO data on cropland (arable and permanent crops) plus pastureland to form their respective land productivity measures. They also used estimates of the total economically active (male and female) population in agriculture obtained from FAO to form their respective labor productivity measures.

Comparing average growth rates in the respective output measures developed by Alston, Beddow, and Pardey in Chapter 3 with the corresponding decadal growth rates of the FAO production index used by Fuglie in Table 7 of Chapter 4 reveals largely similar, but not identical, results. For example, the FAO index has aggregate output for sub-Saharan Africa growing at 2.81% per year for the period 2000-2007, compared with 1.55% per year in Alston, Beddow, and Pardey.[9] In contrast, for the same periods, the FAO production index for the United States and Canada grew at a rate below that implied by the data underlying Alston, Beddow, and Pardey (i.e., 1.04% versus 1.44% per year respectively). Similar discrepancies occurred for an Australia and New Zealand aggregate and an FSU aggregate for most of the decades after 1980. The reasons for these discrepancies are hard to discern. Although both the FAO series used by Fuglie and the Alston, Beddow, and Pardey measure are gross measures of agricultural output, the commodity coverage is different, and it is also likely that the relevant data were downloaded at different times and thus could reflect (sometimes substantial) revisions to the underlying source data.[10]

[9]Fuglie's sub-Saharan Africa totals exclude South Africa, whereas Alston, Beddow, and Pardey report a sub-Saharan Africa total inclusive of South Africa. Excluding South Africa from the Alston, Beddow, and Pardey sub-Saharan Africa total yields an output rate of growth of 1.58% per year. In addition, Fuglie calculates his terminal period growth rates for the years 2000-2007, whereas Alston, Beddow, and Pardey span the period 2000-2005.

[10]In addition, Fuglie applied a smoothing procedure to his output series before calculating growth rates, whereas Alston, Beddow, and Pardey did not adjust their series before estimating rates of growth using the log difference method.

The results of Alston, Beddow, and Pardey are limited to partial productivity measures. Fuglie also reports measures of TFP. Using FAO data for 171 countries for 1961-2007, Fuglie (p. 91) finds "no evidence of a general slowdown in sector-wide agricultural TFP, at least through 2007. If anything, the growth rate in agricultural TFP accelerated in recent decades, due in no small part to 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." Fuglie (p. 92) also notes that "it is also clear that agricultural productivity growth has been very uneven. . . . TFP growth may in fact be slowing in developed countries while accelerating in developing countries."

To develop his TFP estimates, Fuglie had to address a host of data and measurement problems of the types mentioned at the beginning of this chapter.[11] Fuglie was very conscious of these issues, and much of his effort was spent trying to minimize their undesirable consequences. He was not able to compute an approximation to a Divisia index (such as a Fisher ideal index or a Tornqvist-Theil index), but rather he used a growth accounting approach in which measures of proportional changes in individual inputs and outputs were weighted by their shares of cost or revenue, respectively, in a base year. This approach will result in index number biases, but it is difficult to predict the direction let alone the size of the resulting distortion in the measure of TFP. For a considerable number of countries, data on these shares were not available, so Fuglie applied (fixed and constant) shares from selected countries for which measures were available to countries for which they were not. The distortions resulting from this approximation are not easy to predict. For some input categories, data on quantities were not available so he applied the growth rate for a subset of the category (e.g., riding tractors within the category of all machinery and all other capital) as an estimate of the growth rate of the entire category. This approach will lead to biases if the item used as a proxy is growing at a significantly different rate compared with the other elements of the category. The use of the count of tractors is likely to be a downward biased measure of the quantity of tractor services because the quality of tractors has generally improved.

Such measurement problems are unavoidable if the FAO data are to be used to derive country-specific estimates of TFP. Fuglie's efforts to address these many

[11]Many of these data and measurement issues were identified initially by Schultz (1956) and Griliches (1963) and have been the subject of continuing efforts in the more recent literature, as discussed by Alston et al. (2010), for example.

challenging measurement problems are admirable and his estimates are probably as good as can be made with the available resources, but concerns remain.[12] One check on Fuglie's estimates is to compare them with those for which more complete data are available, which Fuglie did for eight countries. Among those eight, three exhibited statistically significant differences in TFP growth rates, compared with Fuglie's own in Chapter 4. The remaining five showed differences in TFP growth rates that might be economically important, even if not statistically significant. Fuglie drew some reassurance from the comparison but this is not to say that the comparison implies an endorsement of any of his specific findings. And for those countries for which we have detailed results reported in country-specific chapters in this volume based on more complete data, better methods, or both, we would put more weight on those results.

Against this background, it is not clear how much weight should be placed on particular findings based on measures of TFP of the types estimated by Fuglie, particularly in relation to the question of a slowdown in productivity growth. Measuring the growth rate of TFP is difficult. Testing for a slowdown, which requires measuring significant changes in growth rates between periods, is more difficult. That this is so is illustrated in the studies reported in this volume that had access to better and more complete (but still not ideal) data and that were able to use the best methods. Moreover, the types of indexes computed by Fuglie might be relatively ill-suited for testing for structural changes over time in growth rates as they have inherent biases that are time-dependent—because they use fixed, base-period shares to weight quantities, because they omit certain categories of inputs, and because they do not accommodate changes in the quality and composition of capital.[13] Fuglie's estimates are the only available estimates of agricultural TFP growth for many countries of the world in the recent period. Even so, they should be used carefully, given the many constraints that data and measurement realities and choices place on generating accurate estimates, and especially in relation to the question of a slowdown in productivity given that we have little basis for assessing their accuracy for that purpose.

[12]For instance, Alston et al. (2010) demonstrated the considerable sensitivity of their U.S. MFP measures to choices of price weights, input quality or compositional adjustments, and measurement methods, sensitivities that are likely to be magnified in efforts to generate MFP measures on an international scale with incomplete and inaccurate measures of agricultural input quantities and prices.

[13]The literature about index number problems and biases has emphasized errors in the "level" or growth rate of the index. Particular types of index number problems may be more serious than others when the issue is errors in the size and significance of changes over time in the measured growth rate, but the literature has not discussed this aspect.

Chapter 5. Mullen presents a range of types of evidence on the patterns of "Agricultural Productivity Growth in Australia and New Zealand." The Australian Bureau of Statistics (ABS) uses national income accounting data to estimate and report value-added measures of productivity for sectors in the Australian market economy, in which the inputs are labor and capital, at five-year intervals. Using this measure, over the period 1986-2006 productivity in the sector comprising agriculture, fisheries, and forestry grew by 3.0% per year, which is 2.5 times the rate of growth for the market economy as a whole. Mullen finds no evidence of a recent slowdown in the ABS measures of Australian agricultural productivity.[14] Likewise, Hall and Scobie (2006) constructed an MFP series for New Zealand agriculture for the years 1927-2001 using a value-added approach. Their measure of MFP for the entire period 1927-2001 grew by 1.8% per year. The average annual growth rates by subperiod were 1.0% (1927-1956), 2.2% (1957-1983), and 2.6% (1984-2001). It is noteworthy that the period of accelerating MFP after 1984 coincides with a period of major economic reform within the New Zealand economy. Using a series published by the New Zealand Ministry of Agriculture and Fisheries, Cao and Forbes (2007) estimated that for the period 1988-2006, MFP in agriculture (not including forestry and fisheries) grew by 2.7% per year, 1.8 times faster than MFP growth of 1.5% per year for the market economy as estimated by Statistics New Zealand. As for Australia, labor productivity in New Zealand agriculture grew more quickly than capital productivity, and total input use declined. There is little evidence from these measures that growth in productivity in Australian or New Zealand agriculture has slowed.[15]

In Chapter 5, Mullen also reports gross value measures based on ABARE farm surveys for "broadacre" agriculture, which includes the extensive grazing and cropping industries, and for dairying from Nossal et al. (2009). These measures show a distinct slowdown in productivity growth in broadacre agriculture. The index of MFP for Australian broadacre agriculture grew at an average annual rate of 1.5% per year over 1978-2007, but it had grown by 2.0% per year or more over the first two-thirds of this period. Productivity growth stalled or went negative in the 10 years to 2007. This decade was characterized by widespread

[14]These value-added measures are "partial" productivity measures in that they explicitly leave out some elements of inputs and outputs that are incorporated in measures based on gross sectoral output.

[15]The Australian MFP growth rates were estimated as the coefficient on the time trend in a regression of the log of MFP against a constant and the time trend whereas the New Zealand counterparts were estimated as the average of annual percentage changes.

drought and poor seasonal conditions generally, which makes it difficult to discern an underlying slowdown in agricultural productivity growth. Productivity growth varied by state, with productivity growth much faster in Western Australia and South Australia than in New South Wales and Victoria, and also varied within broadacre agriculture, with a more pronounced slowdown for cropping than for beef and sheep specialists.

Mullen discusses the contrast in patterns between the ABS value-added measures and the ABARE gross-value measures and concludes that they are broadly consistent given the partial coverage of the value-added measures. The remaining challenge is to interpret the observed substantial slowdown in productivity growth and determine whether it is a temporary consequence of poor seasons—such that the prior path of productivity growth will be restored in the event of a return to historically normal weather patterns—or a more enduring consequence of other factors, such as a change in climate or past changes in research funding.

Chapter 6. Veeman and Gray discuss "The Shifting Patterns of Agricultural Production and Productivity in Canada." Canadian primary agriculture has evolved to a sector characterized by fewer and larger farms. Productivity growth, reflecting both technological change and economies of size and scale associated with farm consolidation and specialization, has been an important factor in this evolution. Both the study of Canadian crop yields and the analysis of TFP growth in the crops sector in the Prairie region of Western Canada indicate a slowdown of productivity growth in crop production since 1990. Since the early 1960s, the yields of several major crops have increased by approximately 60%. Yield trends for corn, wheat, canola, and peas exhibit consistent absolute growth in yields but declining proportional rates of growth over the period. Labor productivity in crop and animal production in Canada grew rapidly at 4.7% per year from 1961 to 2005. TFP growth for crops and livestock was considerably slower, ranging from 0.6% per year based on gross output to 1.4% per year based on value added. In Western Canada's Prairie region, productivity grew by nearly 1.6% per year since 1940. Crop productivity growth outpaced that of livestock historically, but not from 1990 to 2004. Slower growth in agricultural R&D in Canada and at the Prairie level seems to underlie slower agricultural productivity growth, at least in the crops sector, in the past two decades.

Chapter 7. One of the first studies to report a slowdown in agricultural productivity growth in recent times was done by Thirtle et al. (2004), with reference to the United Kingdom. More recent UK evidence is presented by Piesse and

Thirtle in this volume in their chapter on "Agricultural Productivity in the United Kingdom." The average annual change in TFP from 1953 to 1992 in the United Kingdom was 1.53%. The average annual change in the following decade was 0.4%. Average annual growth in TFP picked up again from 2003 to 2008 to 1.0%, but the cause of this increase was a dramatic decline in reported agricultural labor. Piesse and Thirtle argue that this decline in labor probably reflects an unmeasured influx of agricultural workers from the new European Union member states. If this argument holds true, then the recent surge in TFP growth is illusory.

Piesse and Thirtle argue that a slowdown in TFP growth was caused primarily by four factors, three of which could be quantified. The first is a slowdown and retargeting of public R&D. Growth in public agricultural R&D ended in 1982. And a growing proportion of available funds were retargeted away from cost-reducing and production-enhancing research toward basic research and public interest research, which includes research on environmental and animal welfare issues. The second was a slowdown in domestic private R&D research activity, which seems to be a complement to public R&D research. About half of the impact of a decrease in private R&D was made up for by increased applications of foreign-developed technology. The third factor was a reduction in the growth of farm size, which limited the efficiency gains that accrue from larger farms. And fourth, Piesse and Thirtle note that decreases in farm-level efficiency measures coincided with the general slowdown in productivity growth, and they draw an association between these patterns and the fact that free extension advice was eliminated in 1988. A resulting decline in efficiency and productivity growth could have been expected if farmers undervalued such technical advice and chose not to pay for the optimal amount of advice, or if private sector extension advice was a poor substitute.

Chapter 8. The case of the United States was featured to some extent by Alston, Beddow, and Pardey, who in Chapter 3 discussed patterns in U.S. commodity prices, yields, and other partial productivity measures that were consistent with a slowdown in productivity growth since 1990. In their analysis of "The Shifting Patterns of Agricultural Production and Productivity in the United States" in Chapter 8, using state-level MFP measures, Alston, Andersen, James, and Pardey also found compelling evidence of a slowdown in agricultural productivity growth since 1990.

U.S. agricultural production changed remarkably during the past 100 years. Changes in production and productivity were enabled by dramatic changes in the quality and composition of inputs, important technological changes resulting from agricultural research and development, and wholesale changes in the structure of the farming sector. Reflecting rapid growth in productivity, the quantity of U.S. agricultural output grew nearly 2.5-fold during the period 1949-2002, even though the measured quantity of aggregate input use declined marginally.

While U.S. agricultural productivity grew quickly through the 1980s, mounting evidence indicates a substantial, sustained, systematic, structural slowdown in the growth rate of U.S. agricultural productivity since then. Over the period 1949-1990, MFP grew positively in all 48 contiguous states, whereas during the period 1990-2002, MFP growth was negative for 15 states, mostly in the northeast. MFP grew faster in the more recent period compared with the earlier one in only 4 states, with 44 states experiencing lower rates of productivity growth. U.S. aggregate agricultural productivity grew on average by just 0.97% per year over 1990-2002 compared with 2.02% per year over 1949-1990. The simple average of the 48 state-specific MFP growth rates indicates a larger difference between the periods, a paltry rate of 0.54% per year for 1990-2002 compared with 2.02% per year for 1949-1990. This slowdown in productivity growth is statistically significant and economically important.

Chapter 9. Jin, Huang, and Rozelle discuss "Agricultural Productivity in China."[16] According to FAO estimates, China represented 22.5% of the value of global agricultural production in 2005, sufficient to have a meaningful impact on the global aggregate picture. Like many other elements of the economy, agricultural productivity in China has followed its own path, not always in step with the rest of the world, particularly reflecting the changing political regimes and changing government policies. In this chapter, the authors describe the productivity trends in China's agricultural sector during the reform era that began in the 1980s, with an emphasis on the period 1995-2005. The authors discuss the influence of changes in government investments in research and extension as well as the dramatic transformations in the agricultural sector.

China's agricultural economy has been steadily transforming from a grain-first sector to one producing higher-valued cash crops, horticultural goods, and livestock and aquaculture products. In the early reform period, output growth—driven by increases in yields—was experienced in all subsectors of agriculture, including grains. However, since the mid-1990s, the area sown to

[16]This summary draws heavily on the *Choices* article by the same authors (i.e., Jin, Huang, and Rozelle 2009), which itself summarizes the story presented in Chapter 9.

rice and wheat production has fallen, as has the domestic production of these two staple food crops. The contraction in grain supply was preceded by a reduction in demand as increasing per capita incomes, rural to urban migration, and a reduction in government marketing controls has shifted the pattern of consumption away from staple food grains. Like the grain sector, production of cash crops in general and specific crops, such as cotton, edible oils, and vegetables and fruit, also grew rapidly in the early reform period, but in contrast to staple grain crops the output of these other crops continued to grow throughout the reform era beginning in the 1980s, some at rates in excess of 5% per year. The growth in livestock and fishery output outpaced the growth in output from the cropping sector, in total and in most of the crop subcategories. Livestock production increased by 9.1% per year in the early reform period and has continued growing at between 4.5% and 8.8% per year since 1985. Fisheries production increased by more than 10% per year during 1985-2000, and the combined share of livestock and fisheries in total agriculture rose to 45% in 2005, more than doubling their 1980 share.

In Chapter 9, Jin, Huang, and Rozelle used data envelopment analysis methods to estimate commodity-specific rates of TFP growth for different subperiods. Their estimates indicated that, for early and late indica rice and soybeans, TFP grew by an average of 1.8% per year during 1985-1994, slower than in earlier years. The TFP growth rate was smaller for wheat and corn, and negative for japonica rice (it declined by 0.12%) per year from 1985 to 1994. TFP growth during 1995-2004 was positive for all 23 commodities and in all cases was faster than for the previous period. With just a few exceptions, TFP growth for these commodities exceeded 2% per year after 1994. The implied rate of growth of TFP for Chinese agriculture exceeded 3% per year during 1995-2004. Coupling these estimates with the corresponding TFP estimates for 1978-1994 implies that TFP growth in China over the period 1978-2004 sustained an average rate of growth in excess of 3% per year, a remarkable achievement over a quarter of a century. The rate of increase in agricultural TFP in China over 1978-2004 was high by historical standards and compared with corresponding rates of TFP growth reported for many other countries around the world. Agricultural TFP in China grew at a relatively rapid rate since 1995 for a large number of commodities. TFP for the staple commodities generally increased by about 2% per year; TFP growth rates for most horticulture and livestock commodities were even higher at between 3% and 5% per year.

Jin, Huang, and Rozelle ascribe much of this TFP growth to changes in the technologies flowing to and being used by these sectors. Both domestic and foreign technologies have played a role. A significant part of the rapid changes in technology and productivity reflected the adaptation and adoption of technologies from other countries. Such catching-up innovations, which involve adopting superior technologies in use in other countries, may allow relatively rapid productivity growth for a time, but they are more one-shot changes by nature (albeit spread over a number of years) rather than continuing innovations yielding sustained compound growth. It remains to be seen how much of China's relatively rapid agricultural productivity growth can be sustained after the catching-up process has become more nearly complete and a series of important institutional reforms—beginning with the switch from collectivized to more individualized forms of production agriculture, that is, the so-called Household Responsibility System that was introduced in the late 1970s—have run their course. Similarly, the broad capital intensification and labor-saving changes in Chinese agriculture will have diminishing impacts on agricultural productivity as the process of change diminishes.

Chapter 10. As in China, changing political regimes and policies have had profound impacts on the "The Shifting Patterns of Agricultural Production and Productivity in the Former Soviet Union and Central and Eastern Europe," which is the subject of Chapter 10 by Swinnen, Van Herck, and Vranken.[17] Agricultural output and productivity have changed dramatically in Central and Eastern European countries (CEECs) and the FSU since the fall of the Berlin Wall, exactly 20 years ago.[18] Initially, market reforms caused a strong decline in agricultural output. In the first years of transition, gross agricultural output decreased in all countries by at least 20%. The transition from a centrally planned economy to a market-oriented economy coincided in all countries with subsidy cuts and price liberalization, which in general caused input prices to increase and output prices to decrease. In response to the new relative prices, the use of

[17]This summary draws directly from the *Choices* article by the same authors (i.e., Swinnen, Van Herck, and Vranken 2009), which itself summarizes the story presented in Chapter 10.

[18]The review covers more than 20 countries, which the authors organized into six regional groups: Central Europe (Hungary, Slovakia, Czech Republic, and Slovakia), Baltics (Estonia, Lithuania, and Latvia), Balkans (Albania, Bulgaria, Romania, Slovenia), European CIS (Commonwealth of Independent States) (Russia, Ukraine, Belarus), Transcaucasia (Georgia, Armenia, Azerbaijan), and Central Asia (Uzbekistan, Turkmenistan, Kazakhstan, Kyrgyz Republic, and Tajikistan).

inputs decreased and so did agricultural output. The extent to which this output decline was associated with changes in productivity depended on the speed with which labor could exit agriculture, and agricultural factor and output markets could develop. These, in turn, depended on the initial conditions and the reform policies that were implemented, both of which were very different across countries in the region. Swinnen, Van Herck, and Vranken document the changes, explain how they were affected by a combination of factors, and identify four "patterns" of productivity changes that they relate to differences in initial conditions and reform policies.

The most economically advanced countries in Central Europe and the Baltics, such as Hungary, the Czech Republic, Slovakia, and Estonia, implemented radical reforms. These countries were characterized by relatively high incomes, a capital-intensive agricultural sector, and a big-bang approach to reforms and privatization, including restitution of land to former owners. The loss from forgone economies of scale was limited because the restitution of agricultural land to previous owners led to consolidation of land in large farming enterprises. In addition, a massive outflow of agricultural labor occurred early in transition, facilitated by a well-developed social safety net system and radical reforms, which stabilized the macroeconomic environment. This outflow of labor caused substantial gains in labor productivity early on in transition. Later, productivity gains were reinforced by spillovers from the large inflow of foreign direct investment (FDI) in the agri-food sector. Investments, through vertically integrated supply chains, improved farmers' access to credit, technology, inputs, and output markets.

Another pattern was followed by the poorer CEECs, including Romania, Bulgaria, Lithuania, and Poland. These countries were diverse in their initial farm structure. Before transition, Poland already had mainly small family farms, whereas in Lithuania, Romania, and Bulgaria the agricultural sector was concentrated in large corporate farms. However, in all four countries, labor outflow from agriculture was limited in the first years of transition. In these countries, agriculture served as a social buffer in times when overall unemployment was high and social benefits were low. The restitution of land to former owners constrained access to land for young farmers, since that land was given to older people who started farming to complement their small pensions. Because the agricultural sector in these countries was relatively capital-intensive, the break-up of the corporate farms into small family farms caused significant losses in economies of scale and yielded only limited gains from the shedding of labor. Initially, both output and productivity declined. In countries such as Poland and Lithuania, output and productivity started to recover in the mid-1990s stimulated by FDI. In Romania and Bulgaria, output and productivity recovered only slowly, and at the end of the 1990s they decreased again as a result of the financial crisis. From the beginning of the twenty-first century the outflow of inefficient labor and the inflow of FDI started a sustained recovery.

Third, a group of poor Transcaucasian and Central Asian countries, such as Armenia, Azerbaijan, Kyrgyz Republic, and Tajikistan, followed yet another pattern. These countries are characterized by their poverty and the absence of a good social safety net system, their labor-intensive agricultural systems, and their slower progress in overall reforms. In these countries, agriculture also provided a buffer role and a labor sink. Reforms caused a strong shift from large scale toward individual farming—especially when land distribution in kind to households was introduced after the failure of the share distribution system became evident. The reforms also caused a substantial inflow of labor into agriculture and growth in the importance of more labor-intensive sectors, such as horticulture and livestock. This caused a decrease in labor productivity while land productivity grew. Although there has been substantial growth in yields, labor productivity is still now substantially below pre-reform levels in Transcaucasia.

A fourth pattern is followed by a group of middle-income FSU countries, including Kazakhstan, Russia, and Ukraine. In these countries, there was almost no outflow of agricultural labor and, since output fell substantially in the 1990s, agricultural labor productivity declined strongly. Reforms were implemented only slowly and soft budgets continued, which favored the large-scale farms and constrained restructuring, with limited efficiency gains. Only after the Russian crisis in 1998 did the macroeconomic situation improve, with enhanced competitiveness of the domestic agricultural sector through exchange rate devaluations and the inflow of revenues from increasing oil and mineral prices. This affected in particular Russia and Kazakhstan. Ukraine implemented a series of important reforms in the late 1990s. Since then, agricultural productivity has increased in these countries as liquidity in the economy and investments in agriculture increased. Surplus employment started to decline gradually. An important factor in the growth of productivity beginning in 2000 was increased investments in the food industry, which benefited agriculture through vertical integration. It took more than 15 years in the European CIS for labor and land productivity to recover to their pre-reform levels.

Chapter 11. Singh and Pal discuss "The Changing Pattern and Sources of Agricultural Growth in India." The pace of growth of the Indian economy has accelerated over recent decades, averaging less than 5% per year during the 1980s and 1990s and more than 7% per year during the period 2003-2007. In contrast the agricultural economy has performed erratically. As the technologies of the green revolution spread throughout the country and rural public investments (in agricultural R&D, extension, and rural infrastructure) grew, agricultural output expanded rapidly, beginning mainly in the irrigated areas during the 1970s and then extending to rain-fed agriculture beginning in the 1980s. However, beginning in the early 1990s, agricultural output growth slowed and fell well below the corresponding rate of growth of the non-agricultural sector. It has also been subject to large year-to-year (often weather-induced) fluctuations.

The composition of agricultural output has changed substantially over recent decades. The crop sector, including food staples such as rice, wheat, millet, and sorghum along with higher-valued horticultural crops, still accounts for the preponderance of agricultural output—more than two-thirds by value in 2008. Nonetheless, the livestock sector grew from a market share of less than one-fifth in the early 1980s to around a one-quarter share in 2008. India is now the world's largest producer of milk, and poultry meat and egg production has increased markedly over recent years. Output diversification extended beyond the changing crops-livestock shares to also affect the commodity mix within these broad sectors. As average per capita incomes rapidly rose, urbanization rates grew, female literacy and participation in the workforce increased, and agricultural trade expanded, the demand for Indian agricultural outputs also changed, and supply responded to meet these new demands. The growth in production of cereals (mainly rice and wheat) and pulses has slowed, while production of fruits and vegetables has picked up pace, as has the production of flowers, sugar, and molasses. Cotton production is notable, with strong growth performance in recent years made possible by significant advances in seed technologies, especially the rapid uptake of Bt cotton varieties.

Singh and Pal present some summary evidence on the patterns of PFP and TFP growth and discuss the sources of output growth, but the evidence is mixed depending on the measures, time periods, and regions within the country being considered, making general patterns difficult to discern. They observe that, as a general rule, yield growth contributed more than area expansion to the growth in output for most crops. Yield growth generally slowed during the 1990s compared with the 1980s, although for some crops yield growth recovered in the period 2001-2007. None of the reported productivity studies provides evidence on Indian agricultural TFP growth beyond the latter half of the 1990s, ruling out the prospects of assessing contemporary developments in these broader productivity metrics. They are also too few in number and lack consistency in coverage and methodology to make for much of a meaningful summary, other than the observation that for the years they do cover—specifically various periods during the 1960s, 1970s, and 1980s—the majority of the reported TFP growth rates were at the upper end of the spectrum that is typically reported, often well more than 2.0% per year.

Chapter 12. In his chapter on "Indonesia: From Food Security to Market-Led Agricultural Growth," Fuglie presents and evaluates new agricultural input, output, and productivity estimates for Indonesia in the period 1961-2006 and places that evidence in a long-run policy context. Economic developments in Indonesia have noteworthy and important global consequences. Indonesia is the world's fourth most populous nation, and by 2005 had graduated to a lower-income country with per capita income averaging $3,209. In agricultural GDP terms it is also now the fifth-largest agricultural producer in the world.

Real agricultural GDP nearly tripled from the early 1960s to 2001-2005, while in quantitative terms agricultural output expanded by a factor of five from 1961 to 2006, equivalent to an annual average growth rate of 3.62% per year. Rice production still dominates the food sector. It accounted for around half the country's total agricultural output (measured in "rice-equivalent" units) during the period 2001-2005 and occupied almost 29% of the cropped area in 2005. However, estate crops such as oil palm, rubber, sugarcane, and cacao, along with livestock, capture aquaculture, and horticultural production, have all increased in importance. Much of the growth in estate crops, especially oil palm production, which is now the second-most important commodity (again in "rice-equivalent" units) in Indonesia, took place off Java, especially on the islands of Kalimantan, Sumatra, and Sulawesi. A notable feature of Indonesian agriculture is that total cropland area expanded at an average rate of 1.4% per year over 1961-2005 and is still expanding at more than 1% per year. Irrigated area has expanded too, and now accounts for 23% of the country's total cropland.

Both the quantity and quality of labor used in Indonesian agriculture increased since the early 1960s. The economically active labor force almost doubled from 28 to 51 million persons from the early 1960s to 2001-2005, although many of those persons (especially those working on Java) earned an increasing and now large share of their income from non-farm sources. Growth in manufactured inputs (including fertilizer, machinery, and animal feed) grew rapidly over this same period, albeit from a small base. Fuglie estimates that the quantity of total farm inputs more than doubled over the years 1961-2006, equivalent to an average rate of increase of 1.80% per year.

Looking at land and labor productivity trends, Fuglie identifies a bifurcated pattern of change within Indonesia. In densely populated Java (with 856 persons per square kilometer in 2000), both land and labor productivity grew substantially between the 1960s and 2001-2005. Farmers intensified production through a rapid uptake of green revolution rice technologies beginning in the 1960s and 1970s and later shifted resources into higher-valued horticulture, livestock, and aquaculture production. In contrast, on other islands (primarily Kalimantan, Sumatra, and Sulawesi) land area expansion was the primary source of output growth; land productivity hardly improved, but labor productivity increased as the average cropland per worker rose.

Evidence of average yield growth trends reveals a range of commodity-specific patterns. Rice yields soared during the 1960s and 1970s, but yield growth slowed markedly during the 1990s, and that pattern persists. Soybeans and mungbeans have had little yield growth since the 1960s, while groundnuts have shown a modest growth in yields. Growth in cassava yields has been uneven over time (and the area planted to cassava has trended down so that output has grown slower than yields), although corn yields have shown consistently strong growth in yields since the 1970s. As famers switched from near-subsistence to more commercial modes of operation, coupled with increased use of improved seed, fertilizer, and pesticides, average yields of many fruit crops improved over time.

Combining the aggregate agricultural (i.e., crops, livestock, and cultured fish) input and output measures developed for this study, Fuglie estimates that TFP growth in Indonesian agriculture averaged 1.82% per year for the period 1961-2006. Partitioning this growth into periods demarked by key political, institutional, and policy changes, Fuglie notes that agriculture TFP grew by only 0.54% per year during the political unstable period 1961-1967. During the green revolution period 1968-1992, marked by political stability and substantial input (especially fertilizer) subsidies, TFP grew by 2.35% per year. The Asian financial crises then took hold, and measured TFP growth dropped to just 0.58% per year for the period 1993-2001 but rebounded to average 2.95% per year in the period

2002-2006, which Fuglie characterizes as a “liberalization” period in which market forces played a larger role in allocating resources to and within agriculture.

Chapter 13. Liebenberg and Pardey discuss “Changes in South African Agricultural Production and Productivity,” drawing on a range of new long-run input, output, and productivity measures developed by one of the authors of this chapter (see Liebenberg 2010) plus evidence on South African MFP trends based on estimates gleaned from various other studies. To the extent possible, they also place productivity developments within South Africa into a broader sub-Saharan Africa context.

The twentieth century saw substantive shifts in the structure of agriculture and agricultural production in South Africa. Average farm size grew, farm numbers eventually declined, and production increasingly emphasized higher-valued commodities. The quantity of total agricultural output grew at an average annual rate of 2.56% over 1911-2008, but growth slowed since the 1980s (to just 1.52% per year for the period 1982-2000), largely as a result of a slowdown in the rate of growth in field crop production. Output growth rebounded a little in recent years to average 2.07% per year since 2000. The commodity composition of agricultural outputs in South Africa has also changed, with higher-valued horticultural crops gaining market share at the expense of (staple food) crops and livestock products. The composition of input use has changed, too. Notwithstanding high levels of rural unemployment, during the second half of the twentieth century, and particularly beginning in the 1980s, South African agriculture substantially increased its use of material inputs and continued to invest significantly in capital inputs while the use of labor in agriculture declined.

Liebenberg and Pardey extend an earlier MFP series developed by Thirtle, Sartorius von Bach, and Van Zyl (1993) to show that South African MFP grew, on average, by an estimated 1.49% per year over the years 1947-2008. The 1970s and 1980s showed the highest rate of growth for the period studied (averaging 3.98% per year over these two decades), substantially higher than the 0.62% per year rate reported for the immediate post-WWII decades. However, MFP growth stalled during the period 1981-2008 (to average just 0.76% per annum during these years), reflecting a decline in the rate of output growth coupled with an increase in the rate of input use in agriculture. Thus, since the early 1980s, MFP growth has fallen well below the corresponding rate of population growth. Moreover, the slowdown in MFP over the past several decades mirrors slowdowns in productivity growth rates for both land and labor.

Factor use and productivity patterns in South Africa are not especially representative of realities elsewhere on the continent. For example, the average value of output per unit of labor in 2007 was $5,663 per worker (2000 prices) in South Africa, $1,576 per worker in Nigeria, and just $641 per worker for the rest of Africa. South Africa is distinctive in that its land-labor ratio increased from 39.1 hectares per worker in 1961 to 56.9 hectares per worker in 2007 (implying more pronounced growth in labor versus land productivity), whereas in almost all the other regions in sub-Saharan Africa considered by Liebenberg and Pardey, real output per worker stagnated or (in the case of Eastern and Southern Africa excluding South Africa) actually declined, although land productivity in all regions improved over time. In addition, South African agriculture ended the period with fewer agricultural workers than it had in 1961, whereas the economically active population in agriculture in the rest-of-Africa regions (like their populations generally) grew in the range of 0.19% to 2.49% per year. Consequently the region's generally low land-labor ratios have continued to decline and now fall within a range of 2.33 to 9.34 hectares per worker. It is difficult to envisage how output per worker can be raised substantially, especially given the generally poor rural infrastructure and other market and environmental constraints that limit the transition to higher-valued forms of agricultural output throughout the region. However, it is also difficult to conceive how the chronic hunger and serious bouts of food insecurity that befall many people throughout Africa can be ameliorated if agricultural productivity fails to pick up pace.

Chapter 14. Lence provides an in-depth look at "The Agricultural Sector in Argentina: Major Trends and Recent Developments." In contrast to most of the country-specific chapters, Lence does not attempt to estimate MFP. Rather, he reviews existing estimates and demonstrates that the methods used, the time period examined, and the data source all greatly influence estimates of annual growth in productivity. Studies that have compared TFP estimates from the 1960s and 1970s to the 1980s and 1990s disagree on whether productivity was higher or lower in the later periods. Because of the difficulty in obtaining a consistent set of input data over time for Argentina by which more consistent estimates of TFP could be made, Lence focuses his attention on identifying the major forces at work in Argentina that have determined how the sector has evolved over time.

Lence argues that the most important factor affecting Argentina's agricultural sector is government policy. He shows that a sharp reduction in the extent to which agriculture was taxed in the 1990s led to dramatic increases in the use of fertilizer and pesticides, adoption of technologies, the conversion of new lands into crop production, and adoption of more intensive livestock feeding operations. Per hectare yields of soybeans and corn increased notably during the late 1990s. Lence attributes the soybean yield increases to adoption of the complementary package of no-till and glyphosate-tolerant soybeans. Further evidence of productivity increases since 1990 is the sharp increase in milk production per cow from around 2,000 kg per cow per year to almost 5,000 kg per year. This increase came about through better genetics, improved milking machines, and improved pasture productivity.

The case of Argentina illustrates the importance of government policy in determining the extent to which farmers are willing to invest in new technologies and inputs. Drawing on his knowledge about Argentina's agriculture along with available production estimates, Lence demonstrates that the relaxation of agricultural taxes in the 1990s led to a surge in production and productivity, although existing TFP estimates do not all reflect such an increase. Whether the resumption of high export taxes that accompanied the Argentine financial crises in 2001 and 2002 will reverse some of these gains remains to be seen. So far, available data suggest that productivity and production do not yet reflect a significant reversal.

4. CONCLUSION

Agricultural productivity is interesting and important but surprisingly difficult to measure meaningfully and discuss in simple and definitive terms. Concepts range from simple and commonplace partial productivities, such as crop yields, to the all-encompassing TFP. Often analysts are interested in quantifying the rate of technological change, for developing a sense about the economic performance of the sector and the competitive position of one region or country vis-à-vis another. For such purposes, the TFP is the most relevant concept, but TFP is not a synonym for technological change, and PFPs and MFPs can be informative about both technological change and the sources and nature of change in TFP. TFP can also be influenced by changes in the spatial location of production within a country or region; changes in economic efficiency of farms reflecting economies of size, scale, or scope; changes in institutions; or changes in infrastructure. The implications of a change in TFP can depend on the source of the change. In addition, measurement issues have implications for interpretation of the measures. At best we can measure MFP indexes that may be only rough approximations in some cases for the TFP concept we have in mind.

In practice, even the simplest productivity notions can be fraught with difficulty of measurement and interpretation once we allow for the complexities of heterogeneous inputs and outputs and multiyear production processes. In the typical MFP approximations to TFP, various issues arise from the fact that the available data on prices or quantities are incomplete or pre-aggregated, giving rise to various kinds of index number bias, or are inadequate for some other reason. The importance of these aspects varies from case to case—from study to study, time to time, and place to place. This makes it hard at times to compare results among cases.

In this book we are particularly interested in whether agricultural productivity has slowed recently. The evidence is somewhat mixed, reflecting in part the differences in availability of data among countries and time periods as well as other differences in measures and methods not dictated by data alone. The mixture also reflects the fact that agricultural productivity growth is not uniform over space and time. Even so, a few simple lessons have emerged. First, the rate of growth of crop yields has slowed in the past 20-30 years compared with the previous 20-30 years for the world as a whole, but with some significant variation among countries and among commodities. In this context, the recent rate of crop yield growth is generally higher in China and Latin America than in the rest of the world, and generally slower in the developed countries as a group. Similar patterns are evident for other PFP measures. Second, the rate of MFP growth appears to have slowed in the developed countries for which better quality measures are available (i.e., the United States, the United Kingdom, Canada, and Australia). Comparable measures are not available for many countries. Third, even if we can be confident that we see evidence of a slowdown in productivity growth, the interpretation of the finding may not be clear. For instance, the Australian slowdown has been observed during the most severe and extended drought in that country's history. Other countries, too, may have been affected by a run of unusually favorable or unfavorable growing seasons. And it is hard also to tell the difference between sustained changes in growth and the multiyear effects of a change that is really episodic in nature (e.g., the massive institutional reforms in China and the former Soviet Union).

Finally, however, even though we have many reasons for being cautious in this area and we have to weigh mixed and sometimes competing pieces of evidence, we cannot escape the conclusion that agricultural productivity growth has slowed, especially in the world's richest countries. At a minimum, given its importance, this finding is reason for further investigation into the issue. It also is reason for asking whether the current global investment in agricultural R&D will be sufficient to enable the development of innovations and productivity such that agricultural supply will grow fast enough to keep pace with the inevitable growth in demand.

REFERENCES

Alston, J.M., M.A. Andersen, J.S. James, and P.G. Pardey. 2010. *Persistence Pays: U.S. Agricultural Productivity Growth and the Benefits from Public R&D Spending.* New York: Springer.

Alston, J.M., J.M. Beddow, and P.G. Pardey. 2009a. "Mendel versus Malthus: Research Productivity and Food Prices in the Long Run." Department of Applied Economics Staff Paper No. P09-01, University of Minnesota, January (revised September).

———. 2009b. "Agricultural Research, Productivity, and Food Prices in the Long Run." *Science* 325(4, September): 1209-1210.

Alston, J.M., and J.S. James, 2002. "Price Policies and the Domestic and International Distribution of Commodity Quality: Theory and Application to EU Wheat." In *Global Food Trade and Consumer Demand for Quality,* B. Krissoff, M. Bohman, and J.A. Caswell, eds. Boston: Kluwer Academic Publishers.

Alston, J.M., G.W. Norton, and P.G. Pardey. 1998. *Science under Scarcity: Principles and Practice for Agricultural Research Evaluation and Priority Setting.* Ithaca, NY: Cornell University Press (republished by CAB International).

Alston, J.M., and P.G. Pardey. 2007. "Funding Trends for Research and Extension and the Future of U.S. Agriculture." Media advisory for a presentation made at the Cultivating Our Competitive Edge "Break and Briefing," organized by the National Coalition for Food and Agricultural Research (C-FAR), Longworth House Office Building, U.S. Congress, Washington, DC, March 13.

Beddow, J.M. 2010. "An Economic Assessment of the Spatial Dynamics of U.S. Crop Production and Yields." Unpublished PhD dissertation, University of Minnesota (in preparation).

Cao, K., and R. Forbes. 2007. "Productivity in the New Zealand Primary and Downstream Sectors." *Australasian Agribusiness Review* 15(Paper 9): 120-133.

Diewert, W.E. 1976. "Exact and Superlative Index Numbers." *Journal of Econometrics* 4(2): 115-145.

FAOSTAT Database. http:/faostat.fao.org. United Nations Food and Agriculture Organization, Rome.

Griliches, Z. 1963. "The Sources of Measured Productivity Growth: Agriculture, 1940-1960." *Journal of Political Economy* 71(4): 331-346.

Hall, J., and G.M. Scobie. 2006. "The Role of R&D in Productivity Growth: The Case of Agriculture in New Zealand: 1926-27 to 2000-01." New Zealand Treasury Working Paper 06/01, Wellington, New Zealand.

Huffman, W.E., and R.E. Evenson. 1992. "Contributions of Public and Private Science and Technology to U.S. Agricultural Productivity." *American Journal of Agricultural Economics* 74(3): 751-756.

———. 1993. *Science for Agriculture: A Long-Term Perspective.* Ames, IA: Iowa State University Press.

Hulten, C.R. 1986. "Productivity Change, Capacity Utilization, and the Sources of Efficiency Growth." *Journal of Econometrics* 33(1-2, October-November): 31-50.

James, J.S. 2000. "Quality Responses to Commodity Policies." Unpublished Ph.D. dissertation, University of California, Davis.

Jorgenson, D.W., and Z. Griliches. 1967. "The Explanation of Productivity Change." *Review of Economic Studies* 34(July): 249-283.

Liebenberg, F. 2010. "South African Agricultural Productivity and Research Performance in the Twentieth Century." Unpublished Ph.D. dissertation, University of Pretoria (in preparation).

Morrison-Paul, C.J. 1999. *Cost Structure and the Measurement of Economic Performance: Productivity, Utilization, Cost Economies and Related Performance Indicators.* Norwell, MA: Kluwer Academic Press.

Nordhaus, W.D. 2004. "Retrospective on the 1970s Productivity Slowdown." NBER Working Paper No. 10950, National Bureau of Economic Research, Washington, DC.

Nossal, K., S. Zhao, Y. Sheng, and D. Gunasekera. 2009. "Productivity Movements in Australian Agriculture." *Australian Commodities* 16(1): 206-216.

Olmstead, A.L., and P.W. Rhode. 2002. "The Red Queen and the Hard Reds: Productivity Growth in American Wheat, 1800-1940." *Journal of Economic History* 62(4): 929-966.

Ramankutty, N., A.T. Evan, C. Monfreda, and J.A. Foley. 2008. "Farming the Planet: 1. Geographic Distribution of Global Agricultural Lands in the Year 2000." *Global Biogeochemical Cycles* 22(January). http://www.agu.org (accessed May 5, 2009).

Ramankutty, N., and J.A. Foley. 1999. "Estimating Historical Changes in Global Land Cover: Croplands from 1700 to 1992." *Global Biogeochemical Cycles* 13(4): 997-1027.

Roeger, W. 1995. "Can Imperfect Competition Explain the Difference between Primal and Dual Productivity Measures? Estimates for U.S. Manufacturing." *Journal of Political Economy* 103(2): 316-330.

Schultz, T.W. 1956. "Reflections on Agricultural Production Output and Supply." *Journal of Farm Economics* 38: 748-762.

Thirtle, C., L. Lin, J. Holding, L. Jenkins and J. Piesse. 2004. "Explaining the Decline in UK Agricultural Productivity Growth." *Journal of Agricultural Economics* 55(2): 343-366.

Thirtle, C., H. Sartorius von Bach, and J. Van Zyl. 1993. "Total Factor Productivity in South Africa, 1947-1991." *Development Southern Africa* 10(3): 301-318.

You, L.Z., and S. Wood. 2005. "Assessing the Spatial Distribution of Crop Areas using a Cross-Entropy Method." *International Journal of Applied Earth Observation and Geoinformation* 7(4): 310-323.

MATRIC
The Midwest Agribusiness Trade Research and Information Center
www.matric.iastate.edu