The Shifting Patterns of Agricultural Production and Productivity Worldwide

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

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Acronyms and Abbreviations

ABARE	Australian Bureau of Agricultural and Resource Economics
ABS	Australian Bureau of Statistics
AEM	Association of Equipment Manufacturers
AgGDP	Agricultural gross domestic product
ALP	agricultural labor productivity
BSE	bovine spongiform encephalopathy
CACP	Commission for Agricultural Costs and Prices (India)
CAP	Common Agricultural Policy
CEECs	Central and Eastern European Countries
CIS	Commonwealth of Independent States
CNBS	China National Bureau of Statistics
CRP	Conservation Reserve Program
DEA	data envelopment analysis
DEFRA	Department for Environment, Food and Rural Affairs (United Kingdom)
EC	European Community
EU	European Union
FAO	Food and Agriculture Organization (of the United Nations)
FDI	foreign direct investment
FSU	former Soviet Union
GDP	gross domestic product
GNI	gross national income
ha	hectare
ICAR	Indian Council of Agricultural Research
IPRs	intellectual property rights
mha	million hectares
MAFF	Ministry of Agriculture, Fisheries and Food (United Kingdom)

MFP	multifactor productivity
MOA	Ministry of Agriculture (Indonesia)
NASS	National Agricultural Statistics Service (U.S. Department of Agriculture)
NRA	nominal rate of assistance
NSDP	net state domestic product
PFP	partial factor productivity
R&D	research and development
RRA	relative rate of assistance (to agriculture)
SAGE	Center for Sustainability and the Global Environment
SSRs	Soviet Socialist Republics
TE	triennium ending
TFP	total factor productivity
USDA	U.S. Department of Agriculture

CHAPTER 1

Introduction and Overview

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

The predominant feature of agricultural commodity markets, since at least the 1950s, has been falling real prices, which can only come about if supply grows faster than demand. The source of much of the supply growth has been rapid growth in agricultural productivity. Recent high commodity prices combined with increased price volatility have raised concerns about whether the price structure has permanently changed. Can we expect a return of falling food commodity prices to a long-term trend like that of the latter half of the twentieth century? Has the path permanently shifted? Or had the trend rate of decline in prices already begun to slow before the recent spike in global prices?

The demand side of the world food equation is relatively uncontroversial and reasonably predictable: population and income growth will lead to sustained increases in the demand for food over the next 40 years. The long-term issues turn mainly on the future path of agricultural supply, in particular, the growth of agricultural productivity given increasing constraints on the natural resource base available for food production. Can we expect global agricultural productivity to grow at rates like those of the second half of the twentieth century or has the rate of productivity growth generally slowed? Certainly some evidence has begun

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to emerge suggesting a slowdown in agricultural productivity in some parts of the world. What is the nature of that evidence? Is the pattern common among all, or even many, countries? Such questions, motivated mainly by an interest in the long-run supply and demand balance for food commodities, provide one motivation for this book. Related questions concern the implications of differential productivity paths among countries for comparative advantage and competitiveness in agricultural commodity markets.

In this book we assemble a range of evidence from a range of sources with a view to developing an improved understanding of recent trends in agricultural productivity around the world. The fundamental purpose is to better understand the nature of the long-term growth in the supply of food and its principal determinants. We pursue this purpose from two perspectives. One is from a general interest in the world food situation in the long run. The other is from an interest in the implications of U.S. and global productivity patterns for U.S. agriculture.

The approach in this book is opportunistic. The project was conceived in January 2009 as something that could be completed within a year, based primarily on research that was already underway or recently completed. We set out to draw on a significant body of such work, conducted in and applying to different parts of the world, to provide a reasonably broad picture of global agricultural productivity patterns. In such an approach, primarily drawing on independently conducted pre-existing works, it is not possible to make the elements totally consistent, compatible, and coherent in terms of their methods and emphasis. We had to take many aspects of the individual studies as essentially given. In addition, the nature of available data varies enormously around the world, so even if we had the opportunity to design the elements in advance, we would not have been able to standardize methods, measures, and approaches very much. Even so, the results and stories are to a great extent comparable across the individual chapters, though not without some significant differences.

Almost all of the chapters use datasets that end in the beginning or the middle of the first decade of the twenty-first century. Such a common endpoint anchors the chapters and makes the results somewhat comparable. In all of the studies the emphasis is on discerning longer-run trends in input, output, and productivity (and any systematic shifts in those trends), with some studies providing evidence for three to four decades, others extending back to the middle of the twentieth century, and some stretching back to almost the beginning of that century.

Most of the chapters in this book relate to productivity patterns in individual countries or groups of countries. Three of the chapters take a global perspective. These three chapters comprise Part 1 of the book. The spatial structure and location of agricultural production varies over time both between and within countries, with implications for agricultural production and productivity. In Chapter 2, Beddow, Pardey, Koo, and Wood use data on the evolving spatial patterns of agricultural production to provide a context for the other chapters that follow. Next, in Chapter 3, Alston, Beddow, and Pardey present a range of information on prices and productivity around the world. Using U.S. commodity prices as an index of global prices, they show that the rate of decline in deflated food and feed commodity prices had slowed significantly since 1990. Similarly, various partial productivity indexes, such as grain yields or land and labor productivity, showed significant slowdowns in their growth rates since 1990, albeit with significant exceptions in some places—in particular Latin America and China. In Chapter 4, Fuglie presents some alternative measures of global, regional, and country-specific agricultural productivity patterns, based on the use of Food and Agriculture Organization data to compute measures of multifactor productivity or total factor productivity (MFP or TFP). He concludes there is no evidence of a general slowdown in sector-wide agricultural TFP growth rates. The contrast in results between these two chapters is striking and demands an explanation. The role of differences in data, estimation methods, and other aspects of the respective treatments of the data in contributing to such contrasts is discussed in Chapter 15.

The main part of the book is in Part 2, which contains a total of 10 chapters, providing country-specific evidence. These chapters cover countries for which work had been done recently that we considered to be both of suitable nature and quality for inclusion in this volume, and relevant for understanding the phenomena of interest. They cover Australia and New Zealand (Chapter 5, by Mullen), Canada (Chapter 6, by Veeman and Gray), the United Kingdom (Chapter 7, by Piesse and Thirtle), the United States (Chapter 8, by Alston, Andersen, James, and Pardey), China (Chapter 9, by Jin, Huang, and Rozelle), the Former Soviet Union and Eastern Europe (Chapter 10, by Swinnen, Van Herck, and Vranken), India (Chapter 11, by Singh and Pal), Indonesia (Chapter 12, by Fuglie), South Africa (Chapter 13, by Liebenberg and Pardey), and Argentina (Chapter 14, by Lence). The most significant omissions are Brazil and the countries of Western Europe as well as most of Africa. Otherwise the coverage is quite broad and representative and accounts for a great share of global agricultural production.

In a few countries, data are available to allow the computation of indexes of MFP using suitable measures of prices and quantities, with reasonably complete coverage of inputs and outputs. In the case of the United States, detailed data are available to measure aggregate MFP for individual states in long time series (Chapter 8). Similarly good aggregate national data are available for the United Kingdom (Chapter 7), parts of Canada (Chapter 6), Australia and New Zealand (Chapter 5), and South Africa (Chapter 13), although among them there are important differences in details. In the case of China (Chapter 9), the authors present estimates of TFP at the level of individual commodities whereas for other countries such measures are typically available for an aggregate of total agriculture or for a substantial aggregate (e.g., "broadacre" agriculture in Australia; crops versus livestock in Canada). In other countries, only crop yields and other partial productivity measures are available. But for those countries for which we have a range of measures available, they tend to tell similar stories—that is, partial productivity measures and MFP or TFP show similar patterns. To the extent that this is expected to be true for other places for which we do not have complete measures, we can draw crude inferences from the available evidence for what the more complete measures would show.

Chapter 15 concludes the book with a summary and, to the extent possible, a synthesis of findings across the chapters comprising this volume. As noted, the different chapters were commissioned from authors who had independently conducted the underlying research; they were not coordinated in advance. Consequently the chapters exhibit significant differences in style, coverage, methods, and issues, some of which were dictated by the nature of the available data and by differences in relevant issues among countries. Across the chapters, along with different concepts and measures of inputs, outputs, and productivity, different approaches were used to test for a slowdown, and to some extent different approaches may have contributed to some differences in findings. These contrasts raise several questions: What is the appropriate measure of productivity? What is the appropriate method to test for a slowdown? What is the appropriate interpretation of a slowdown and its likely causes? What are the policy implications? These questions are addressed in Chapter 15.

Part 1

International Evidence and Interpretation

CHAPTER 2

The Changing Landscape of Global Agriculture

Jason M. Beddow, Philip G. Pardey, Jawoo Koo, and Stanley Wood

1. INTRODUCTION

Location matters when it comes to assessing agricultural productivity levels and trends. Most find familiarity with the notion that the amount and composition of agricultural output of a particular country or region of the world tends to change over time, but many are less familiar with the spatial dynamics of agriculture. The spatial structure and location of agricultural production both between and within countries, which we dub the landscape of agriculture, also varies over time. Agriculture is an inherently spatial process, with yields (and hence output) being greatly influenced by local factors such as weather and climate, soils, and pest pressures. Consequently, agricultural production and productivity are especially sensitive to spatial and inter-temporal variations in natural factors of production. As we do in this chapter, giving more explicit attention to the spatial dimensions of agriculture and how they change over time deepens our under-

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standing of the production and productivity performance and potential of this sector. The following section begins by presenting a broad assessment of changes in the global footprint of agriculture over the past three centuries. Agriculture is continually on the move, and this spatial volatility has profound implications for how productivity metrics can and should be interpreted.

Consideration of explicitly spatial patterns is useful, but additional insights can be gained by conducting analyses across meaningful spatial aggregations. Such spatial aggregations summarize certain attributes of space that affect agricultural production and productivity. For example, assessing production in terms of geopolitical aggregates is helpful since national or subnational borders help delineate the boundaries of economic, political, and social factors that affect the production choices made by farmers and other decisionmakers. However, geopolitical boundaries provide a poor proxy for agroecology. Thus, a more complete view of agricultural production can be developed by placing production in both geopolitical and agroecological space, as we do in Sections 3 and 4, respectively. Since movements in the footprint of agriculture necessarily imply underlying changes in the natural and socioeconomic factors that drive productivity, thoughtful interpretation of differences in a productivity metric across time or space requires consideration of the extent to which such changes might or might not be captured by that metric. Therefore, these assessments provide grounding and context for the discussions of productivity in the remainder of this volume.

Agricultural statistics are almost always reported on a geopolitical basis, but analysts are increasingly placing agricultural production in agroecological space. Recent examples include the work of Wood, You, and Zhang (2004) and You and Wood (2005) to develop geo-referenced global crop geographies for the world's principal (food) crops. Ramankutty and Foley (1999) and Ramankutty et al. (2008) have developed long-run geo-referenced maps of the location of crop production worldwide. It is to these sources of data—supplemented with global, commodity-specific production data from FAO—that we turn to assess the spatial dynamics of agriculture from both a geopolitical and an agroecological perspective.

2. SPATIAL DYNAMICS OF GLOBAL CROPPED AREA

While natural inputs play an important, if not defining, role in agricultural production, agriculture is the antithesis of natural. The output and productivity responses to these natural factors are affected by a myriad of human interventions. Choices about what, where, and when to grow or graze are obvious influences. Modifying the physical or environmental landscape—from leveling or terracing fields to adding fertilizer, supplemental irrigation water, or herbicides and pesticides, all the way to hydroponic production in glasshouse controlled environments—is commonplace. Modifying the genetics of crops and animals is also common.[1] For most of the 10,000-year history of agriculture, the purposeful selection and cultivation of crops and animals was without scientific direction. The rediscovery of Mendel's laws of heredity in 1900 gave added impetus to genetic modification in agriculture. The commercialization of hybrid corn in the United States beginning in the 1930s and the release of genetically modified (including transgenic) crops beginning in the 1990s are a continuation of the long history of human-induced genetic modification that is the essence of agriculture. It is the continuously evolving interaction between genes and the environment that underscores the value of a spatially sensitive perspective on agriculture production processes. The history of this evolution begins with the origins of the crops themselves.

Where crops, or their precursor plants, originated and where they are now principally grown are two sides of the same coin. Identifying the centers of origin of cultivated crops, and even whether such centers exist at all, is subject to considerable debate. Perhaps the most well-known line of reasoning started with the work of Vavilov (1926), who proposed that crops had geographical "centers of origin" and identified eight centers of origin based on measures of diversity. As summarized by Harlan (1971), it was later recognized that the centers of origin may differ from centers of diversity, and further, that the process of domestication can be geographically dispersed. A big part of the longer history of agricultural innovation has to do with the human-induced spatial movement of plants and animals. Candolle (1884, p. 2) noted that when it is feasible to do so, people "soon adopt certain plants, discovered elsewhere, of which the advantage is evident, and are thereby diverted from the cultivation of the poorer species of their own country." Further, Candolle observed that the ancient propagation of a number of useful plants in the Mediterranean (by Egyptians and Phoenicians) enabled later migrants to carry West Asian genetic material into Europe at least 4,000 years ago, and that there is evidence of well-established Chinese cultivation of rice, sweet potatoes, wheat, and millets

[1]The domestication of plants and animals distinguishes agriculture from earlier forms of food production, which involved hunter-gatherer activities whereby humans did not typically manage or in other ways knowingly modify (e.g., genetically) the food sources they sought.

as early as 2,700 BC.[2] It is clear that the pre-history of agriculture was driven by human-mediated dispersal and propagation of crop genetic material and therefore that the landscape of agriculture is, and has long been, subject to near continuous change.

Most agricultural production today uses genetic material that had its source hundreds or even thousands of miles away, but this is a comparatively recent phenomenon (Table 2.1). After thousands of years of slow development, slow improvement, and gradual movement of plants and animals, all driven by human action, the rate of change accelerated in the past 500 years. An important event in this history was the "Colombian Exchange" that was initiated when Columbus first made contact with native Americans in the "New World" (Crosby 1987, Diamond 1999). Most of the commercial agriculture in the United States today is based on crop and livestock species introduced from Eurasia (e.g., wheat, barley, rice, soybeans, grapes, apples, citrus, cattle, sheep, hogs, and chickens), though with significant involvement of American species (e.g., corn, peppers, potatoes, tobacco, tomatoes, and turkeys) that are also distributed throughout the rest of the world. The global diffusion of agriculturally significant plants and animals, and their accompanying pests and diseases, has been a pivotal element in the history of agricultural innovation.

The more recent, but still lengthy, spatial history of cropping patterns developed by Ramankutty and Foley (1999) used 1992 satellite-derived land-cover estimates along with historical (geopolitical) crop inventory data and a simple land-cover change model to estimate global cropping patterns back to 1700. Here, we make use of Ramankutty and Foley's long-run cropping data along with a similar global cropland dataset for 2000 (Ramankutty et al. 2008) to draw conclusions about changes in the geography of agricultural production over the last three centuries. These datasets are distributed by the Center for Sustainability and the Global Environment (SAGE) at the University of Wisconsin and for the sake of brevity will hereafter be referred to as the "SAGE" series (see the appendix).

We used a variety of techniques to represent the changing spatial patterns evident in the SAGE data. Figure 2.1, Panels a and b, give a mapped representation of the SAGE data for 1700 and 2000 respectively. Darker shades indicate that greater percentages of each 55.7-by-55.7 kilometer pixel (projected to the

[2]In fact, Fuller et al. (2009) recently reported evidence of the domestication of rice in the Lower Yangtze region of Zhejiang that dates to between 6,900 and 6,600 years ago.

Table 2.1. Regions of origin and current production of major feed, food, and fiber crops

Crop	Center of Origin	Top Five Producing Countries in 2005-07 Country	Production (mmt)	Global Share (percent)
Wheat	Central Asia	China	103.9	17.0
		India	71.0	11.6
		United States of America	53.4	8.7
		Russian Federation	47.4	7.8
		France	35.2	5.8
		Top Five Total	*310.8*	*50.9*
Corn	South Mexico and Central America	United States of America	294.0	40.1
		China	145.7	19.9
		Brazil	43.1	5.9
		Mexico	21.2	2.9
		Argentina	18.9	2.6
		Top Five Total	*523.0*	*71.3*
Rice	India	China	184.4	28.7
		India	139.3	21.7
		Indonesia	55.2	8.6
		Bangladesh	42.3	6.6
		Viet Nam	35.7	5.6
		Top Five Total	*456.9*	*71.1*
Barley	Abyssinia (Ethiopia)	Russian Federation	16.5	12.0
		Germany	11.5	8.3
		Canada	11.0	8.0
		France	10.1	7.3
		Turkey	8.8	6.4
		Top Five Total	*58.0*	*42.0*
Soybeans	China	United States of America	80.6	37.0
		Brazil	53.9	24.8
		Argentina	41.4	19.0
		China	15.8	7.3
		India	8.9	4.1
		Top Five Total	*200.6*	*92.2*
Cassava	South America	Nigeria	44.3	20.2
		Brazil	26.6	12.1
		Thailand	22.0	10.0
		Indonesia	19.6	8.9
		Congo, Democratic Republic of	15.0	6.8
		Top Five Total	*127.5*	*58.1*
Coffee	Abyssinia (Ethiopia)	Brazil	2.3	30.5
		Viet Nam	0.9	11.8
		Colombia	0.7	9.3
		Indonesia	0.7	8.7
		Mexico	0.3	4.1
		Top Five Total	*4.8*	*64.3*

Table 2.1. Continued

		Top Five Producing Countries in 2005-07		
Crop	**Center of Origin**	**Country**	**Production (mmt)**	**Global Share (percent)**
Bananas	Indo-Malaya	India	18.1	23.5
		China	7.0	9.1
		Brazil	6.9	8.9
		Philippines	6.7	8.7
		Ecuador	6.1	8.0
		Top Five Total	*44.8*	*58.3*
Tomatoes	South America	China	32.6	25.8
		United States of America	11.3	8.9
		Turkey	9.9	7.9
		India	8.9	7.0
		Egypt	7.6	6.0
		Top Five Total	*70.3*	*55.6*
Potatoes	South America	China	71.1	22.3
		Russian Federation	37.5	11.8
		India	24.6	7.7
		Ukraine	19.3	6.1
		United States of America	18.9	5.9
		Top Five Total	*171.5*	*53.8*
Apples	Central Asia	China	25.9	40.8
		United States of America	4.4	6.9
		Iran, Islamic Republic of	2.7	4.2
		Turkey	2.3	3.6
		Italy	2.1	3.4
		Top Five Total	*37.3*	*58.9*
Oranges	India	Brazil	18.1	28.4
		United States of America	8.0	12.6
		Mexico	4.1	6.5
		India	3.5	5.6
		China	2.8	4.4
		Top Five Total	*36.5*	*57.5*
Grapes	Central Asia	Italy	8.5	12.7
		France	6.7	10.0
		United States of America	6.3	9.5
		Spain	6.2	9.2
		China	6.1	9.1
		Top Five Total	*33.7*	*50.4*
Cotton	South Mexico and Central America	China	20.1	28.2
		United States of America	12.2	17.1
		India	10.2	14.3
		Pakistan	6.4	8.9
		Uzbekistan	3.5	5.0
		Top Five Total	*52.3*	*73.6*

Sources: Centers of origin are from Schery's (1972) adaptation of Vavilov (1951). See the appendix for sources of production shares.

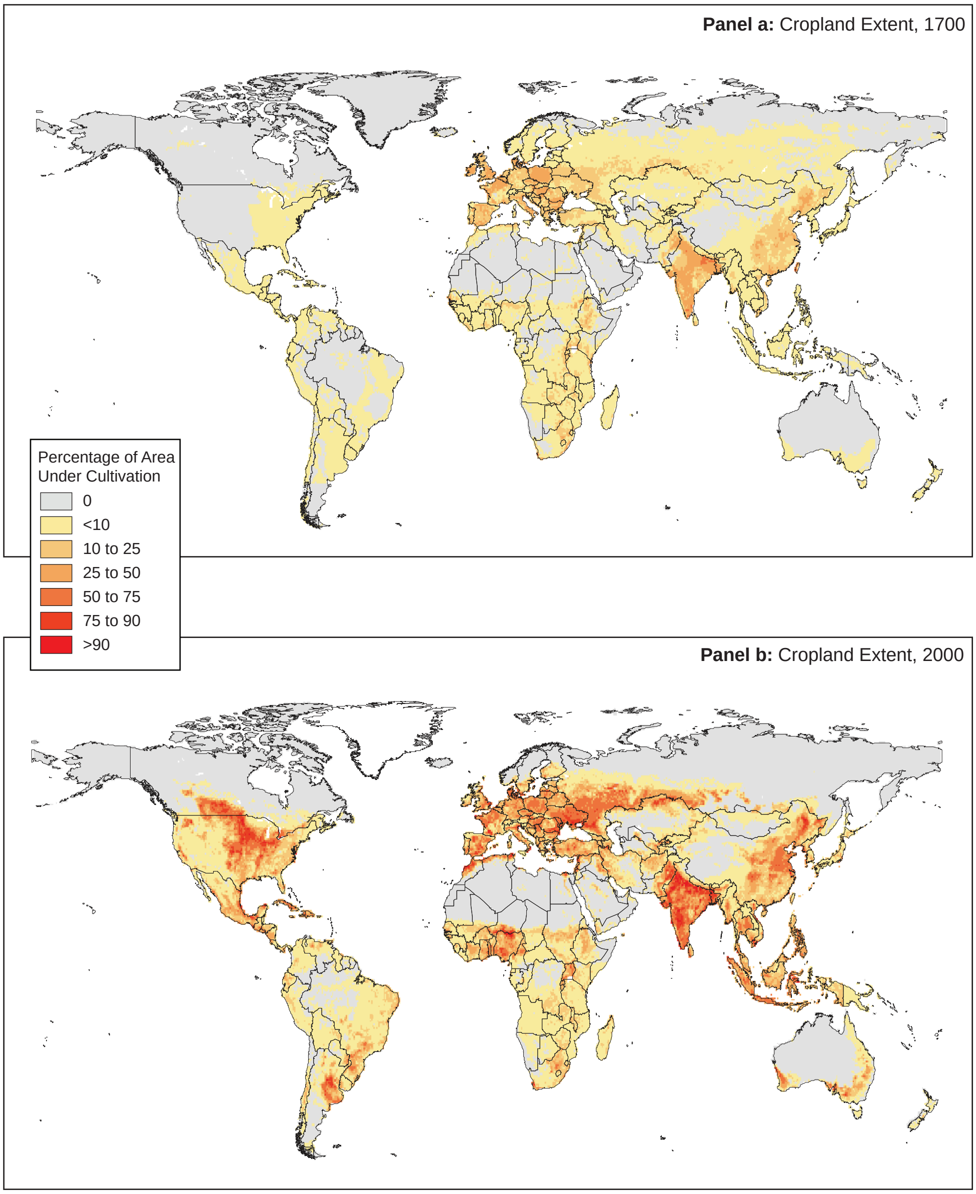
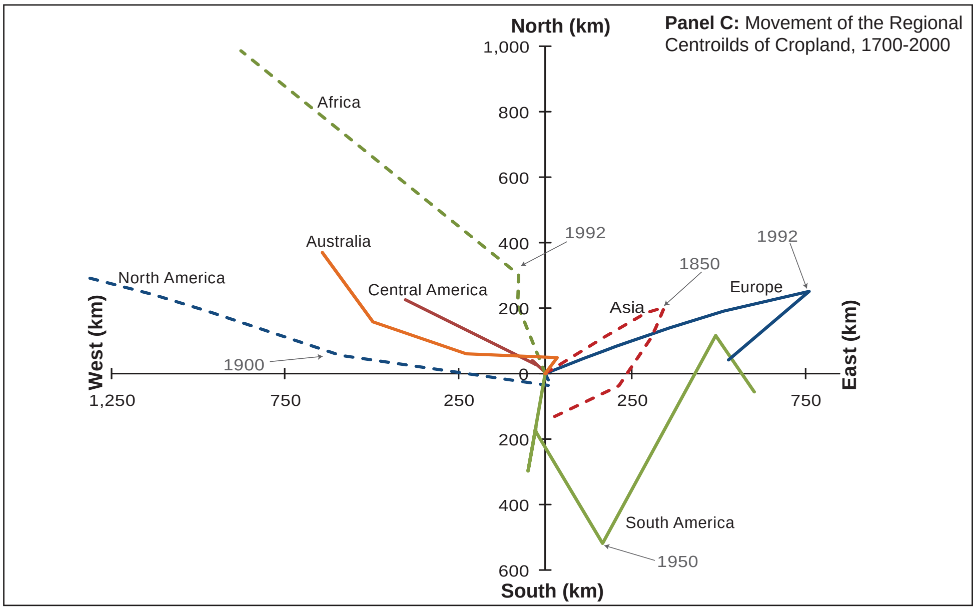


Figure 2.1. Panels a and b. The changing global landscape of crop production, 1700 to 2000

Source: Derived from SAGE data (see the appendix).



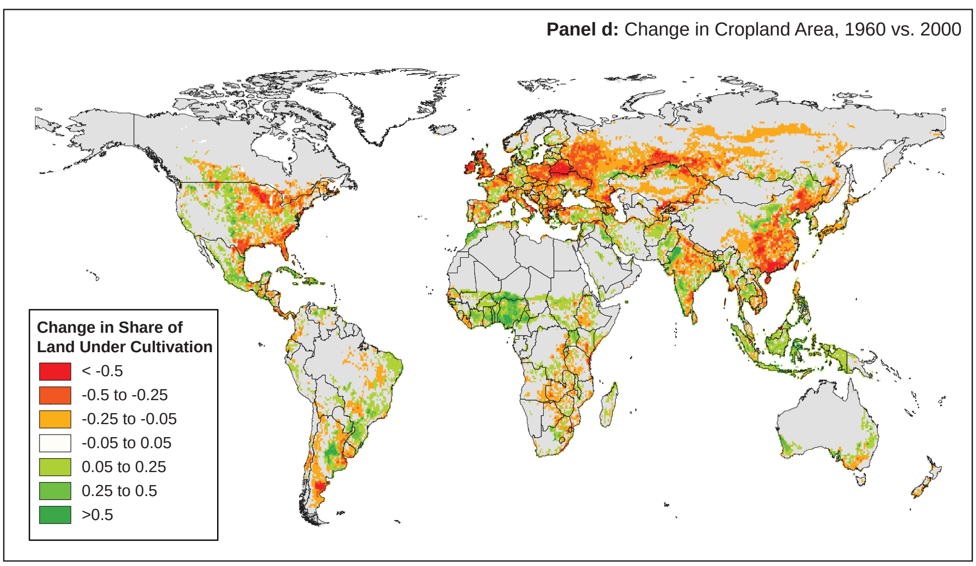


Figure 2.1. Panels c and d. The changing global landscape of crop production, 1700 to 2000

Source: Derived from SAGE data (see the appendix).

equator) are deemed to be cropped. Beginning in 1700, agricultural cropland occupied just 9% of the world's total land area, with most of that cropland located in Asia (accounting for 48.5% of the world's cropped area at that time), Europe (28.5%), and Africa (19.6%). Notably, the sparsely settled New Worlds of Australia, New Zealand, and the Americas collectively accounted for just 3.2% of the land worldwide under permanent crops in 1700. By 2000, the New World share had grown to 27.1% of the total cropped area.

The net effect of the movement of land in and out of cropped agriculture means that agriculture is geographically mobile, particularly when one takes an especially long-run perspective. Figure 2.1, Panel c, provides an indication of the distance and direction of the spatial relocation of agriculture globally by plotting the movement in the "centroids" or centers of gravity of production by region for the period beginning in 1700 (when each region's centroid is centered on a zero latitude-longitude grid coordinate) through to 2000. Each centroid is an estimate of the geographic center (center of mass) of the cropped area in the corresponding region. The location of the centroid itself is not particularly enlightening, and it could easily be the case that a centroid is in a location that does not produce any crops at all, or is otherwise not representative of the general agricultural situation in a country. However, movements in the centroid are revealing as an indication of the influences of changing patterns of settlement, infrastructure, and technologies on the location of agriculture.

According to these data, North America and Africa have seen the largest movements in their production centroids, both shifting about 1,300 kilometers over the 300-year period. As was the case with the other continents, most of this movement occurred after 1900. However, the year 2000 centroids for other regions more or less represent a continuation of the trend from 1950 to 1992; the only anomaly seems to be in Africa, where almost all of the measured movement in its centroid occurred between 1992 and 2000.[3] The Asian centroid moved the least, changing by only 15 kilometers to the east and 137 kilometers to the south.

[3]It seems more likely that the year 1992 and 2000 datasets were not fully conformable than that a massive structural shift in African production occurred during this period. However, the northward movement of agriculture in sub-Saharan Africa is consistent with the finding of Liebenberg, Pardey, and Kahn (2010) that the farmed area in South African agriculture peaked at 91.8 million hectares in 1960, then declined steadily to 82.2 million hectares by 1996, where it has since been more or less stable.

Except in Africa and Asia, the general trend favored movement in longitude rather than latitude. The pronounced northward movement in Africa was almost matched by an equivalent move westward, and, while the Asian centroid showed much more absolute movement along the east-west axis, the net movement over the period was almost due south. Averaging across all of the regions, the net longitudinal movement was 4.6 times as large as the net latitudinal movement. This pattern is related to an argument by Diamond (1999, p. 185), who stated that "localities distributed east and west of each other at the same latitude share exactly the same day length and its seasonal variations. To a lesser degree, they also tend to share similar diseases, regimes of temperature and rainfall, and habitats or biomes (types of vegetation)." Thus, a variety that is successful at a given location is more likely to be successful at other locations with similar latitude, and therefore a spread along the east-west axis is easier than a spread along the north-south axis.[4] This argument provides insights into the forces underlying the direction of agricultural movements, although the implications for modern movements in *overall* production are less clear. For example, opposite latitudinal movements in different crops may be netted out of an assessment of overall production. Second, Diamond took a very long-run view, looking back to pre-history. Insofar as crop management and varietal improvement technologies are reducing the yield-depressing effects of constraints to agricultural production at the more extreme latitudes, one might expect more recent data to exhibit relatively more movement toward the poles.

Over the past three centuries, agricultural cropland in Asia and Europe did move along an east-west axis, but there was considerable movement along a north-south axis as well. In addition, the direction of Eurasian development changed course. European cropland moved in a northeasterly direction until the early 1990s, then took a U-turn, heading southwesterly during the 1990s, no doubt the consequence of an implosion in Soviet agriculture during this period (see Swinnen and Van Herck in Chapter 10 of this volume). Asia moved simi-

[4]Diamond couched his discussion in the context of social developments stretching back into prehistory. Our assessment of the spatial mobility of cropped agriculture begins in 1700. Developments after 1700 dominate the economic landscape. For example, Maddison (2003) reports that global population was just 603 million in 1700 compared with 6.1 billion in 2001, while global GDP grew from an estimated 371 billion in 1700 to 37 trillion in 2000 (in constant 1990 international dollars). Moreover, most of the increase in the area under crops occurred after 1700, with global cropped area expanding by an estimated 253% since then (from 422 million hectares in 1700 to 1.49 billion hectares in 2000 [Ramankutty and Foley 1999 and Ramankutty et al. 2008]).

larly, following a northeasterly trajectory until the 1850s, and then also took a southwesterly track. As of 2000, the Asian centroid was in north-central Bhutan near the border within China, suggesting that the relative rates and spatial patterns of cropland development in China and India dominate the movement in the region's centroid. However, expanding cropland in Indochina and Indonesia during the latter half of the nineteenth century and throughout the twentieth century would tend to tug Asia's centroid southward.

As one might expect given the way these landscapes were settled (particularly with regard to agriculture), both the North American and Australian centroids moved strongly in a westerly direction. This westward movement came with an evident northerly drift that became more pronounced for North America beginning in 1900 and in 1950 for Australia. Notably, a more northerly direction of development for North American agriculture means cooler climates and shorter growing seasons while for Australia it means movement toward more tropical growing conditions. The more northerly path taken by North American agriculture during the twentieth century coincides with the massive ramping up of institutions and investments pertaining to agricultural research and development (see Alston et al. 2010), suggesting that technological factors began playing a more prominent role in the location of crop production.[5] The same forces may have also been operative in Australia, with increasing attention given to tropical technologies by Australian agricultural research institutions during the twentieth century, overlaid with (and part of) a broader government-sponsored program of infrastructure and economic development that put greater emphasis on the more northerly parts of the country (Davidson 1966 and 1981).

Cropland in Central America[6] shifted northwesterly, as developments in Mexico increasingly dominated that landscape. In stark contrast, South American cropland moved strongly in a southerly direction from 1700 to the 1950s, then dramatically changed course, heading northeast for much of the latter half of the twentieth century as Brazilian agriculture occupied

[5]Settlement patterns and the importation of cold-tolerant varieties help to explain the northerly movement of North American agriculture during the nineteenth century. Twentieth century expansion was much less dependent on opening of new lands and importation of germplasm, and much more dependent on the homegrown development and uptake of new corn varieties, notably the rapid uptake of short-duration hybrid varieties beginning in the 1930s that allowed for more intense production, and that spurred a movement into more northerly areas.

[6]Central America is typically defined as the area of Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, and Panama. We also include Mexico because of its climatic and agricultural-historical similarities with the Central American countries.

an increasing share of the region's cropland (an estimated 25.3% in 1950 and 46.7% in 2000). As in Australia, the South American reversal of direction may stem largely from technological and economic policy developments in Brazil. The country rapidly ramped up its agricultural research capacity during the latter half of the twentieth century (Beintema, Avila, and Pardey 2001), and increasingly targeted that effort to more northerly climes. Spillover technologies from other countries—most notably day-length insensitive soybean varieties developed in the United States (Pardey et al. 2006)—enabled large tracts of land to be opened up for agriculture in the Cerrados region of Brazil. These technological factors were reinforced by a series of national development strategies that also targeted more northerly regions of the country.

Panel d of Figure 2.1 uses the SAGE series to show the change in cropped area over the four decades spanning 1960 to 2000. It indicates the localized movement of acreage in and out of agriculture since 1960, or, more specifically, the change in the area share dedicated to crop production for each of the 259,200 mapped pixels (i.e., a value of -50% indicates that half the acreage in that pixel shifted out of cropping agriculture since 1960). The darker the red shading, the greater the percent decline in cropped area per pixel; the darker the green shading, the greater the percent increase in cropped area per pixel. The collapse of the former Soviet Union is evident in terms of substantial declines in cropped area throughout Eastern Europe. The SAGE data also indicate declines in cropped area in parts of Western Europe, northeastern, southern, and southeastern United States, and significant parts of China.[7] There was a substantial increase in cropped areas throughout the Indochina Peninsula, Indonesia, West Africa, Mexico, and Brazil. The overall picture is one of contracting area under crops in temperate regions and increasing cropped area in tropical parts of the world during the last four decades of the twentieth century.

While the centroid of production provides a sense of the "average" location of production for a region, it is also useful to characterize the spatial dispersion of production. One can summarize spatial dispersion in a variety of ways,

[7]Wood, Sebastian, and Scherr (2000, p. 28) document the reduction in cultivated land in China during the first half of the 1990s, largely attributing this to expanded industrial and urban uses of land. Zhang et al. (2007) imply that this trend continued into at least the early part of the twenty-first century. For example, the authors estimate that 260,000 hectares of Chinese cultivated land was converted to non-agricultural uses between 1991 and 2001.

most commonly by assessing whether observations seem to be correlated with other nearby observations by calculating test statistics such as Moran's I (Moran 1950) and Geary's C (Geary 1954) metric.[8] In the present case, these statistics were calculated for each region in each year and the null hypothesis of spatial homogeneity was rejected for any reasonable degree of certainty, confirming the common-sense expectation that agriculture was not distributed uniformly across any of the continents.[9]

For our purposes, it is perhaps more useful to consider metrics of dispersion that are not explicitly spatial. Economists often analyze income distributions using a methodology first described by Lorenz (1905), who graphed cumulative income distribution against population percentiles. If income were equally distributed among the population, the Lorenz curve would be a 45-degree line through the origin, and the degree to which the curve departs from that line is usually summarized by the Gini coefficient (Gini 1912). Here, we make use of the pixilated landscape (30 arc-minute or 5 arc-minute pixels) inherent in the SAGE series and use Gini's procedure to assess the degree to which crop production is concentrated within each region.[10]

In this spatial context, the calculated Gini coefficients will equal zero if each of a region's pixels contains the same share of the region's agricultural area; the value of the coefficients will increase as agriculture becomes more concentrated in fewer pixels, and a coefficient of unity indicates that all production is in a single pixel.[11] In general, Gini coefficients differ more across regions than within regions over time. In every period, crop production was most spatially concentrated in North America and Australia and was least concentrated in Asia and Central America (Table 2.2). The relatively high coefficients for North America and Australia reflect a relatively low ratio of arable to total land, while the low Central American coefficients reflect the opposite, along with a tendency for

[8]Indeed, it is generally assumed that spatial autocorrelation is present unless there is evidence to the contrary. For example, the "first law of geography" states "Everything is related to everything else, but near things are more related than distant things" (Tobler 1970, p. 236).

[9]To reduce the scope of the problem, the spatial weights required for the calculations were defined using rook contiguity rather than an inverse distance metric. In general, these yield similar results but can differ, especially if production tends to exhibit more global autocorrelation than local autocorrelation. This does not affect the present conclusion.

[10]A 5 arc-minute grid yields pixels (cells) that are of about 86 square kilometers at the equator.

[11]Technically, the Gini coefficient calculated over discrete units (e.g., grid cells) cannot equal one; however, under perfect inequality the Gini coefficient approaches unity as the number of units approaches infinity.

Table 2.2. Spatial dispersion of production by year and region

	Gini Coefficient			3rd Quartile		
Region	**1800**	**1900**	**2000**	**1800**	**1900**	**2000**
North America	0.94	0.88	0.87	4.54	8.71	9.56
Central America	0.68	0.68	0.68	24.77	24.77	25.05
South America	0.77	0.75	0.73	18.17	18.73	13.33
Europe	0.80	0.78	0.76	16.07	16.72	11.47
Africa	0.78	0.78	0.79	16.11	15.99	13.21
Asia	0.75	0.74	0.70	18.41	19.72	20.63
Australia	0.93	0.93	0.90	5.37	5.52	4.96

Sources: See the appendix.
Note: The third quartile shows the percentage of each region's total area accounting for one-quarter of cropland.

relatively non-intensive production. Over time, the Gini coefficients for Africa and Central America were stable, while those for the other regions reflected a decreasing spatial concentration of production, as the agricultural footprint of these areas expanded.

Table 2.2 also displays production quartiles which, as implied by the relatively stable Gini coefficients, are also fairly stable over time. The third quartile shows the percentage of the region's total land area that contains 75% of the crop area. By this measure, the largest changes occurred in North America, which concentrated three-quarters of its cropped area in only 4.5% of its land area in 1800. By 2000, 9.6% of the region's land area constituted the same portion of overall cropped area. However, the increased (but still rather concentrated) spatial dispersion of cropped area in North America is a special case, as the interior of the continent, which is generally favorable for agricultural production, was not heavily settled until after 1800. By contrast, Central American and Asian production remained relatively spatially dispersed over the entire period, while South American, European, and African agriculture all became more concentrated after 1900.

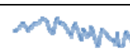
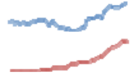
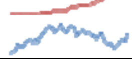
3. SPATIAL DYNAMICS OF GLOBAL CROP PRODUCTION

The previous section explored the long-run, spatially explicit view of agricultural change provided by Ramankutty and Foley (1999) and Ramankutty et al. (2008). We now turn to alternative empirical views of global production for more recent decades by first exploring the commodity- and country-specific data assembled by FAO. These data enable a crop-level assessment of the changing landscape of production within and among countries. Throughout the section, simple economic concepts are employed to provide additional insights that could not otherwise be gleaned from a geopolitical assessment, namely, by considering the interactions between geography, economic development (as measured by income per person), and crop values.

3.1. Global Changes in What Is Produced

Since 1961, a large area has been devoted to the production of cereal crops worldwide, increasing from about 648 million harvested hectares in 1961 to about 700 million hectares in 2007 (roughly 5.6% of the world's ice-free land area, and 55.8% of global harvested hectares).[12] In 2007, oil crops (such as soybeans and rapeseed) had the second-largest physical footprint, with harvested area for these crops totaling around 250 million hectares—more than double the 113 million hectares of oil crops that were harvested in 1961. Over half (52%) of the increased area in oil crops reflects a nearly fourfold increase in the area devoted to soybeans. Table 2.3 shows the trends in area devoted to each of the major crop categories used by FAO. Notably, while area devoted to production of oil crops increased steadily over the period, the area under cereals production increased to a maximum of about 720 million hectares by 1985, then generally decreased until an increasing trend again took hold during the new millennium.

Table 2.3. Global harvested area by crop category

	Area (million ha) and Trend		
Category	**1961**	**Trend**	**2007**
Fiber	38.7		35.8
Fruits	24.5		47.1
Oil crops	113.4		250.5
Pulses	64.0		73.3
Root crops	47.6		54.6
Vegetables	23.7		52.4
Cereals	648.0		699.8

Sources: See the appendix.

[12]This value was calculated based on Ramankutty et al. (2008), who reported that 15 million km^2 of cropland accounted for about 12% of the total ice-free land area in 2000 (which implies that there are roughly 125 million km^2 of ice-free land area).

Further, the total area devoted to pulses, fiber crops, and root crops was little changed, while the areas under fruit and vegetable crops both increased fairly rapidly (with the latter increasing at an increasing rate).

While the land area under cereal production increased from 1961 to 2007, total harvested area over all crops increased even more, so the share of land devoted to cereal production shrank from 67.5% in 1961 to 57.7% in 2007. This was a widespread development, such that the harvested area dedicated to cereals decreased relative to other crop categories in every region of the world except Eastern Europe. The largest changes were in Latin America and North America, which reduced the share of their cropland devoted to cereals by 17.6 and 14.0 percentage points, respectively (Table 2.4). Offsetting this reduction, the same two regions devoted relatively more of their land to oil crops, and in both regions nearly all of the increase in land devoted to oil crops is accounted for by increased soybean production.

3.2. Changes in Where Crops Are Produced

Changes in the global crop mix have been accompanied by changes in the distribution of production among and within countries and regions. Over the past four and a half decades, global cereal output became increasingly concentrated in Asia. This region increased its share of global cereal production from 37.6% in 1961 to 47.2% by 2007, most of which resulted from relatively fast growth of wheat and corn production in China.[13] Over the same period, North American output of cereals grew at about the global average rate, while output in the Former Soviet Union and Europe increased at a slower-than-average rate (2.0%, 0.6%, and 1.4% per year, respectively). Similar patterns were seen for

[13]Here the aggregate production of cereals, fiber crops, fruits, vegetables, roots, and pulses is a simple sum of the quantity of production (by weight) of each crop in a particular crop category. This measure of the aggregate quantity of production is affected by changes in the composition of the aggregate, with subtle but substantive implications for assessing changes in crop productivity (and, notably, aggregate cereal yields). For example, average wheat yields in Minnesota in 2007 were 3.0 tons per hectare while corn yielded 9.8 tons per hectare on average. Forming a "total cereals" perspective by simply summing 10 hectares of wheat output (by weight) and 10 hectares of corn output (by weight) would imply a cereal yield of 6.4 tons per hectare. If all the wheat acreage were switched to corn, estimated cereal yields would increase to 9.8 tons per hectare, absent any change in the average yield of corn (or wheat). These compositional effects will confound efforts to interpret changes in measures of aggregate crop productivity when the aggregate quantities of crop output are formed by simply summing the components of the aggregate (as done by FAO and many other analysts). Alston et al. (2010) explore the empirical implications of alternative aggregation methods when analyzing productivity developments in twentieth century U.S. agriculture.

Table 2.4. Share of cropland devoted to various crop types, by region

Region	Year	Fiber	Fruits	Vegetables	Roots	Pulses	Oil Crops	Cereals
				(percentage)				
North America	1961	5.6	1.0	1.4	0.7	0.7	18.0	72.5
	2007	3.2	0.9	1.1	0.5	2.6	33.3	58.5
Latin America and Caribbean	1961	7.2	3.6	2.2	5.2	9.2	13.7	58.9
	2007	1.7	5.2	2.1	3.7	6.4	39.5	41.4
Europe	1961	1.0	7.7	4.0	8.3	6.6	3.9	68.4
	2007	0.6	7.6	3.3	2.6	1.7	18.0	66.2
Former Soviet Union	1961	2.8	1.2	1.3	6.0	2.9	6.4	79.4
	2007	2.5	1.9	2.0	5.0	1.8	13.9	72.9
Africa	1961	4.5	4.3	2.0	8.3	7.1	16.8	57.1
	2007	2.6	4.5	2.9	12.0	10.5	13.7	53.9
Asia	1961	4.3	1.6	3.0	4.1	9.3	12.8	65.0
	2007	3.9	4.0	6.9	3.3	6.9	18.2	56.8
Oceania	1961	0.2	2.2	1.0	2.0	0.4	4.4	89.8
	2007	0.6	1.8	0.7	1.2	6.0	7.8	81.9
World	1961	4.0	2.6	2.5	5.0	6.7	11.8	67.5
	2007	3.0	3.9	4.3	4.5	6.0	20.6	57.7

Sources: See the appendix.

other types of crops, with Asia increasing its share of fiber, fruit, and vegetable production, again reflecting large increases in Chinese production of these types of commodities (Table 2.5).

In addition to considering geopolitical boundaries, it is also useful to delineate the agricultural landscape according to economic factors. To get a sense of how economic development is related to agricultural production, we grouped countries into two categories, "lower income" and "upper income," according to their income per person.[14] Between 1961 and 2007, the lower-income countries increased their share of production of all types of crops except oil crops. These

[14]The World Bank (2009) classifies countries according to their 2008 per capita gross national income expressed in U.S. dollars. The income groups are high income, greater than $11,905; upper-middle income, $3,856-$11,905; lower-middle income, $976-$3,855; and low income, less than $976. To simplify the presentation, we group the low and lower-middle income countries into one category called "lower income" and the upper-middle and high income countries into a second aggregate called "upper income." It may be helpful to keep in mind that the upper-income group includes Brazil and Russia while China and India are included in the lower-income group.

Table 2.5. Share of world crop production, by commodity type, 1961 versus 2007

Region	Year	Fiber	Fruits	Vegetables	Roots	Pulses	Oil Crops	Cereals
				(percentage)				
North America	1961	20.7	10.0	9.1	3.5	2.8	19.4	20.6
	2007	15.5	5.1	4.5	3.1	10.3	13.3	19.8
Latin America and Caribbean	1961	12.1	16.7	4.1	7.1	8.6	7.9	5.4
	2007	6.2	20.5	4.5	7.8	11.2	17.6	7.4
Europe	1961	3.6	30.7	21.6	30.3	9.6	9.8	16.5
	2007	1.7	12.6	7.6	8.5	5.5	8.3	11.7
Former Soviet Union	1961	13.8	2.9	8.3	18.5	9.0	10.4	13.5
	2007	6.5	2.2	4.4	9.8	3.8	4.3	6.7
Africa	1961	7.9	13.9	6.1	10.5	8.7	15.4	5.3
	2007	6.0	12.6	6.2	28.4	18.9	5.6	6.3
Asia	1961	42.0	24.5	50.3	29.7	61.0	36.3	37.6
	2007	63.2	45.9	72.3	41.8	48.3	50.1	47.2
Oceania	1961	0.0	1.3	0.5	0.4	0.1	0.7	1.1
	2007	0.9	1.1	0.4	0.5	2.1	0.8	1.0
Lower Income	1961	48.9	34.1	47.3	37.6	67.6	48.7	37.6
	2007	66.1	55.1	72.3	69.4	65.5	43.8	51.0
Upper Income	1961	51.1	65.8	52.7	62.3	32.3	51.3	62.4
	2007	33.9	44.9	27.7	30.6	34.5	56.2	49.0

Sources: See the appendix.

countries markedly increased their share of fruits, vegetables, cereals, fiber, and root crops. By 2007, lower-income countries produced 55.1% of the world's fruits (by weight), up from 34.1% in 1961. Indeed, the global growth in the quantity of fruit production was driven by a 361% increase in fruit production by lower-income countries (most of which occurred in the richer countries of this group). The lower-income countries also increased their share of vegetable output from 47.3% of production by weight in 1961 to 72.3% in 2007. By contrast, the upper-income countries increased only their share of oil crop production, from 51.3% to 56.2%, largely reflecting changes in Brazil.

The spatial concordance between (changes in) crop area and crop output are not always close. For example, in 2007 nearly 44% of the world's corn output came from North America while that region accounted for only 23.0% of the area devoted to corn. More strikingly, China increased its global share of wheat production from 6.4% in 1961 to 18.1% in 2007, while its share of land devoted to wheat shrank slightly. Such differences in output and area shares reflect differences in average yields (land productivity) across regions. They also reinforce the findings previously mentioned of the substantial spatial relocation in cropped area worldwide, pointing to even greater movement in the location of production for specific crops both among and within countries. This movement has many important economic implications, not least in relation to understanding the fundamental forces driving observed changes in (aggregate) crop production and productivity estimates.[15]

Between 1961 and 2007, the world's fruit and vegetable production area became more concentrated in Asia and, to a lesser extent, Africa (Table 2.6). Asia now accounts for 45.5% of the land devoted to fruit production and 71.5% of the

Table 2.6. Share of world crop area, by commodity type, 1961 versus 2007

Region	Year	Fiber	Fruits	Vegetables	Roots	Pulses	Oil Crops	Cereals
				(percentage)				
North America	1961	16.4	4.8	6.5	1.7	1.3	17.9	12.6
	2007	11.9	2.6	2.7	1.2	4.7	17.8	11.2
Latin America and Caribbean	1961	11.8	9.2	5.8	7.0	9.1	7.6	5.8
	2007	5.8	13.4	4.9	8.1	10.5	19.1	7.1
Europe	1961	2.8	33.7	18.1	18.7	11.1	3.7	11.3
	2007	1.4	14.3	5.6	4.3	2.1	6.4	8.4
Former Soviet Union	1961	10.8	7.0	8.3	18.7	6.7	8.4	18.2
	2007	7.8	4.7	4.4	10.4	2.7	6.2	11.7
Africa	1961	11.6	17.7	8.4	17.4	11.1	14.8	8.8
	2007	14.0	18.7	10.6	42.8	27.7	10.6	15.0
Asia	1961	46.6	26.8	52.4	36.2	60.6	47.1	42.0
	2007	58.7	45.5	71.5	32.8	50.5	39.2	43.9
Oceania	1961	0.0	0.8	0.4	0.4	0.1	0.4	1.3
	2007	0.4	0.9	0.3	0.5	1.9	0.7	2.7
Lower Income	1961	56.9	37.2	55.1	52.4	70.7	59.7	46.6
	2007	71.6	60.4	78.2	76.1	77.4	48.8	56.0
Upper Income	1961	43.1	62.8	44.8	47.5	29.3	40.3	53.4
	2007	28.4	39.6	21.7	23.8	22.5	51.2	44.0

Sources: See the appendix.

[15]A more in-depth assessment of productivity developments worldwide and in specific countries is provided in the following chapters.

land devoted to vegetable production, versus 26.8% and 52.4% in 1961, respectively. This change resulted mostly from increases in Asian fruit production area rather than from decreases elsewhere. Europe's fruit area decreased by 18.5% overall over the period, the net result of a 30.5% decrease in Western Europe and a 62.3% increase in Eastern Europe.

Over the same period, Asia increased its vegetable production area by a remarkable 202.4%. Increased vegetable area in China (18.3 million additional hectares) contributed to this change, although Asia without China still more than doubled its land devoted to vegetable production. A similar percentage increase in vegetable land area was seen in Africa (179.2%), although the continent only managed to keep pace with worldwide increases, maintaining a global share of production of slightly more than 6% during both periods.

3.3. Global Crop Production: An Economic View

In the preceding analyses, the crop categories used to describe changes in the cropped areas and amounts produced were based on quantities (by weight) of crop production aggregated into standard crop categories conceived on the basis of the biology of each crop (e.g., cereals, fruits, root crops, and so on). In this section we re-aggregate the crop quantities into crop categories conceived on the basis of the per unit value of each crop.

To conduct our analysis of the shifting landscape of crops grouped on economic criteria, all 157 crops (and crop products) in the FAO database (FAOSTAT) were classified into three groups, low, medium, and high unit-valued crops according to their average international price during 1999-2001 as reported by Wood-Sichra (2005).[16] Crop values ranged from about $20 per metric ton for sugarcane to nearly $4,500 per metric ton for vanilla. Acreage in low unit-valued crops is dominated by the cereals (wheat, corn, rice, and barley) and soybeans, which account for about 70% of the area in low-value crops. The most important high unit-valued crops (by area) were cotton, coffee, sesame seeds, cocoa, tobacco, and tea while the acreage in medium unit-valued crops was dominated by commodities such as dry beans, various peas, pulses, groundnuts, and olives.

[16]Prices reported by Wood-Sichra are the 1999-2001 average international prices used by FAO to form their production indices (see http://faostat.fao.org/site/612/default.aspx). Crops with an average price greater than $700 per metric ton were classified as high-value crops, while those with prices under $250 per metric ton were classified as low-value crops. Most livestock products would fall in the high-valued class, but here we limit our analysis to a consideration of plant products (not least because area under production is a more straightforward concept for crops versus livestock production).

Between 1961 and 2007, the global share of total cropped area devoted to low- and high-value crop production increased by about the same percentage, 24.2% and 28.5%, respectively. Over the same period, the area devoted to medium-value commodities increased by 68.8% (Table 2.7). Thus, there was a slight shift toward production of medium-value crops, and that shift was evident in both lower- and upper-income countries. However, the nature of the change was different for different types of countries: the importance of medium-value crops increased in the upper-income countries in part because of reductions in high-value crop area, while lower-income countries increased the area of all three classes of crops. This analysis reveals that the decline in harvested area in the Former Soviet Union and Europe resulted from decreases in area under low-value crops (by 38.9 and 20.7 million hectares, respectively) combined with small increases in the area under medium-

Table 2.7. Area by crop value class and region, 1961 and 2007

Region	Year	Value Class Low	Medium	High
			(million ha)	
North America	1961	97.4	3.3	7.2
	2007	115.6	10.4	5.2
Latin America and Caribbean	1961	51.3	7.9	13.2
	2007	115.1	12.1	10.6
Europe	1961	91.2	16.5	2.1
	2007	70.5	19.1	2.2
Former Soviet Union	1961	142.7	4.3	2.6
	2007	103.8	5.0	3.1
Asia	1961	333.6	58.7	24.4
	2007	421.1	95.1	39.6
Africa	1961	76.5	16.0	11.3
	2007	149.1	36.8	17.1
Oceania	1961	9.7	0.2	0.1
	2007	21.5	2.0	0.4
World Total	1961	802.9	106.9	60.9
	2007	996.4	180.4	78.2
Lower Income	1961	380.3	70.0	35.2
	2007	548.5	126.2	56.6
Upper Income	1961	422.6	36.9	25.7
	2007	448.0	54.2	21.6

Sources: See the appendix.

and high-value commodities. Nevertheless, low-value crop area increased overall because of substantial increases in every other region.

4. AN AGROCLIMATIC PERSPECTIVE ON CROP LANDSCAPES

The spatial lens through which we have examined patterns of agricultural production is explicitly geopolitical. Both the national and subnational production data that underpin our analysis are collected and reported according to administrative (geopolitical) boundaries that, while not arbitrary, are demarked with little or no consideration of the agroecological variation that directly affects crop location choices and the production and productivity potentials of these crops. Thus, considering crop production totals aggregated over geopolitical space masks significant spatial heterogeneity within these aggregates that can have important policy and practical consequences.

To illustrate this issue, consider two countries: country A has spatially uniform growing conditions for its 200,000 hectares of rain-fed corn that each yield around 1.5 tons per hectare, while country B contains large extents of more arid areas where 160,000 hectares of production yield a meager 700 kg per hectare under rain-fed production and other more-favored areas where around 40,000 hectares yield 4.7 tons per hectare under irrigation. Both countries report identical national corn production statistics: 200,000 hectares of corn averaging around 1.5 tons per hectare (Table 2.8, Panel a). While the reported corn yields for both countries are identical, this masks the spatial heterogeneity inherent in these geopolitical aggregates, thereby compromising efforts to understand the factors that affect productive performance and variations in productivity over time and among countries.

For example, consider two adjacent countries that equally share 400,000 hectares of corn across a well-watered plain cut by national boundaries that yield some 2 tons per hectare. Additionally one has a further 200,000 hectares under dryland conditions yielding 800 kg per hectare, while the second has some 50,000 hectares of land under irrigation yielding 5 tons per hectare. When presented as national aggregates, their respective average yields of 1.4 tons per hectare and 2.6 tons per hectare suggest quite different production contexts (with perhaps little scope for technology spillover between these two countries) (Panel b of Table 2.8). Yet the common agroecological domain they share is the largest single productive resource, and so the productivity potentials of the two countries have much more in common than

Table 2.8. Spatial aggregation bias: geopolitical versus agroecological units

Geopolitical Aggregation	Agroecological Aggregation	Implications
Panel a		
Country A: 200,000 ha, 1.5 ton ha^{-1}	Country A: Warm, wet lowlands – 200,000 ha, 1.5 ton ha^{-1}	Geopolitical aggregations infer similar production contexts. Agroecological aggregations reveal large differences.
Country B: 200,000 ha, 1.5 ton ha^{-1}	Country B: Hot, semi-arid, poor soils – 160,000 ha, 700 kg ha^{-1} Hot, irrigated, good soils – 40,000 ha, 4.7 ton ha^{-1}	
Panel b		
Country A: 400,000 ha, 1.4 ton ha^{-1}	Country A: Warm, wet plains— 200,000 ha, 2 ton ha^{-1} Hot, semi-arid— 200,000 ha, 800 kg ha^{-1}	Geopolitical aggregations infer dissimilar production contexts. Agroecological aggregations reveal extensive commonalities.
Country B: 250,000 ha, 2.6 ton ha^{-1}	Country B: Warm, wet plains— 200,000 ha, 2 ton ha^{-1} Warm, irrigated, good soils—50,000 ha, 5 ton ha^{-1}	

Source: Developed by the authors.

would be inferred from a consideration of yield relativities absent the agro-ecological information.

Panels a through d of Figure 2.2 show the year 2000 estimates of the global crop geographies for corn, wheat, rice, and soybeans, respectively. In these plots, the larger the share of cropped area per pixel in the indicated crop, the darker the shade. Panel e of Figure 2.2 shows 16 agroecological zones based on moisture and temperature. To reveal some of the within-country variation in the production landscape of agriculture, we overlaid the agroclimatic representation on the respective 2000 global crop geographies for corn, wheat, rice, and soybeans to generate production area and quantity estimates for these four crops stratified by agroclimatic regions within countries. For each crop this generated a spatial regrouping of the area and quantity data for a total of 785 agroclimatic-by-country classifications. To simplify the presentation of these data, the countries were re-ag-

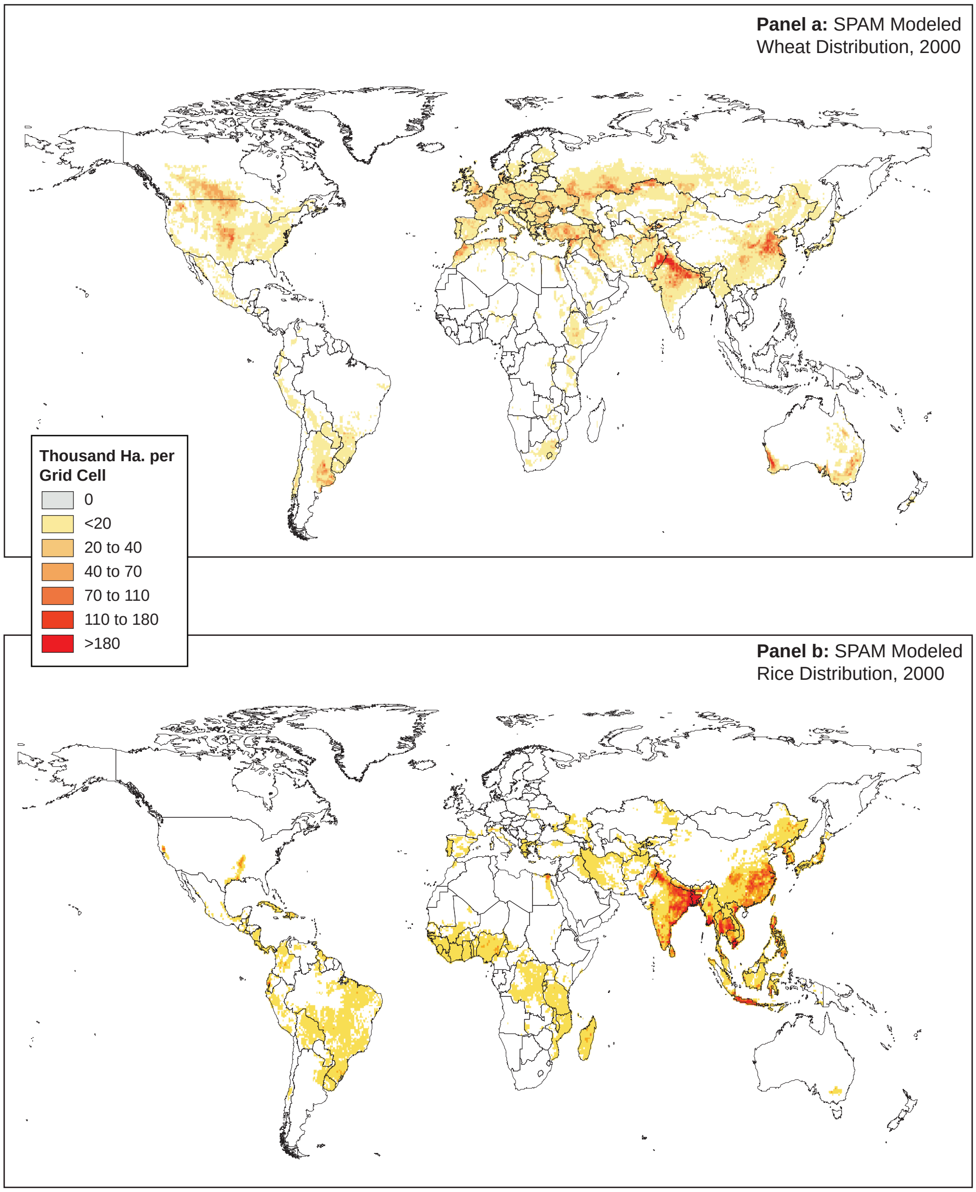


Figure 2.2. Panels a and b. Global agroclimatic zones and year 2000 crop geographies

Sources: Crop allocation data are documented by You and Wood (2005). Global agroecological zones were modified from Sebastian (2006).

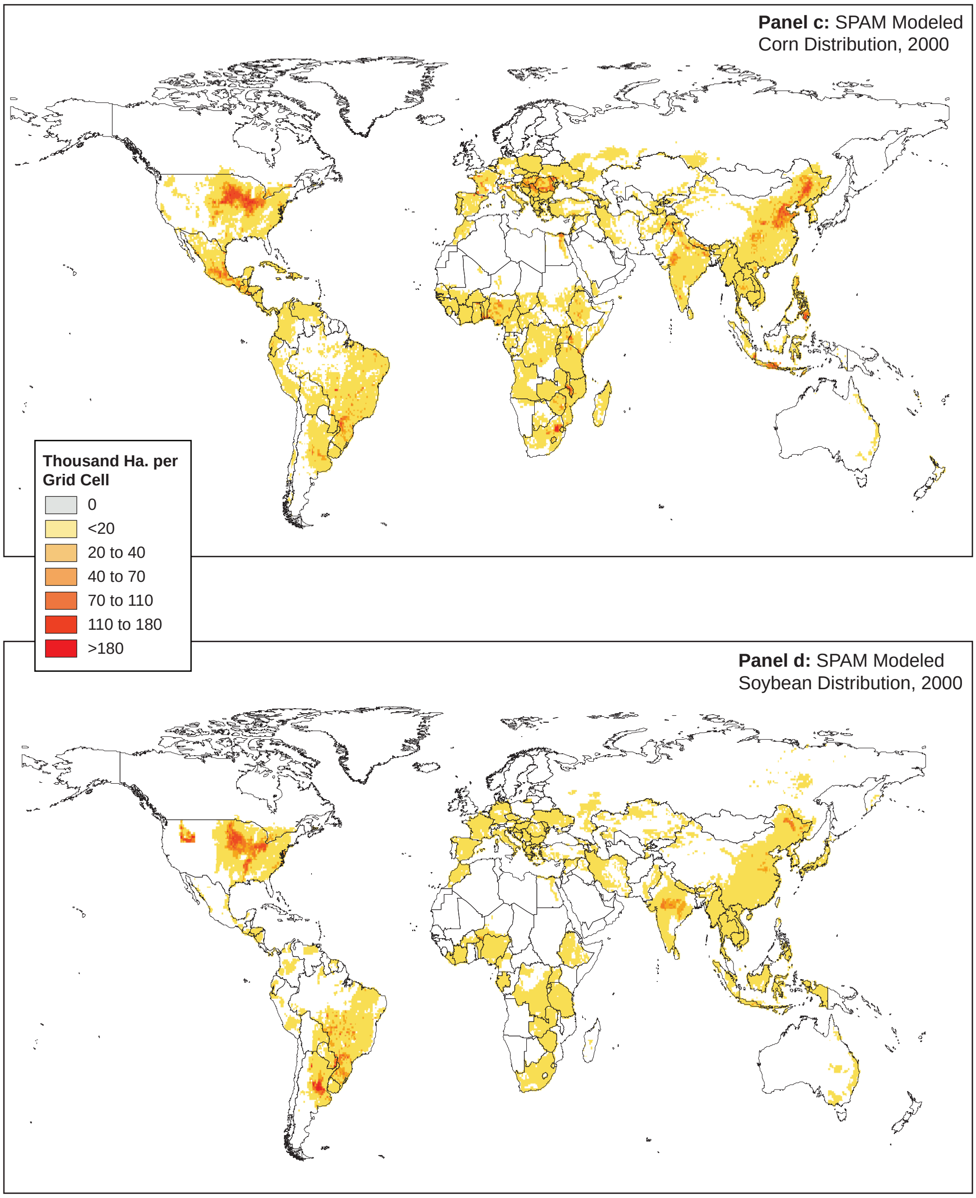


Figure 2.2. Panels c and d. Global agroclimatic zones and year 2000 crop geographies

Sources: Crop allocation data are documented by You and Wood (2005). Global agroecological zones were modified from Sebastian (2006).

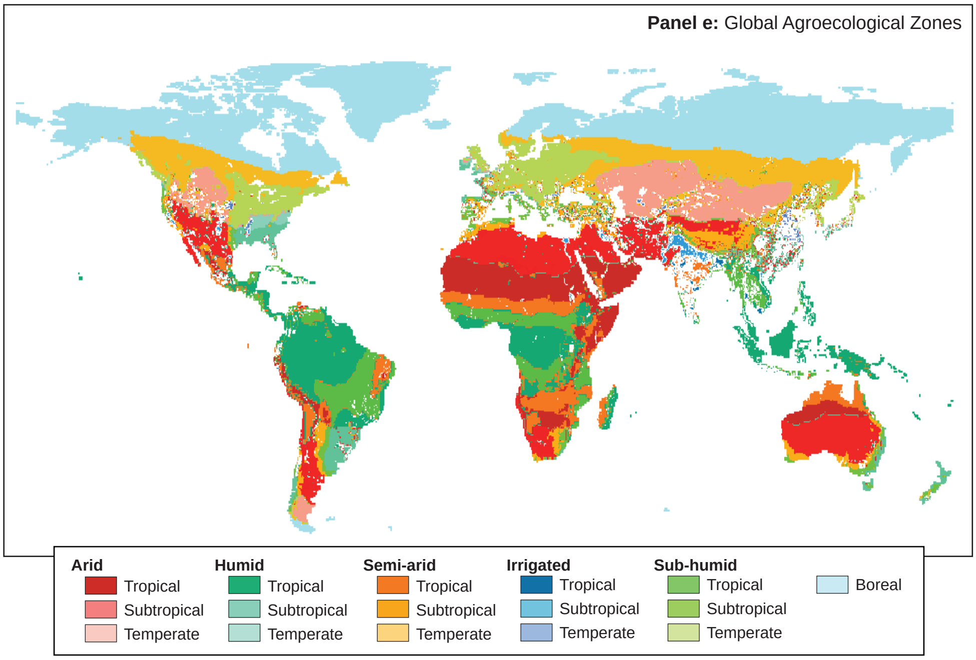


Figure 2.2. Panel e. Global agroclimatic zones and year 2000 crop geographies

Sources: Crop allocation data are documented by You and Wood (2005). Global agroecological zones were modified from Sebastian (2006).

gregated into two geopolitical groups, lower income and upper income (as defined in Section 3), and the pixilated crop geographies within countries were collapsed into three agroclimatic groups: temperate, subtropical, and tropical.

Figure 2.3 summarizes the results of this analysis, with Panel a showing the global area and production shares for each crop for the year 2000, stratified into three agroclimatic regions. Panels b and c preserve the structure of Panel a but include only lower- and upper-income country area and production shares, respectively. The percentages in brackets under the area and output labels at the bottom of these two panels indicate the respective lower- and upper-income country crop shares overall. The preponderance of global rice production in 2000—be it assessed in terms of area harvested or quantities produced—occurred in tropical or subtropical areas, whereas global wheat production and soybean production were split more evenly between temperate and tropical areas. Two-thirds (66%) of the world's corn production came from temperate areas, which accounted for just 43% of the global

Figure 2.3. Corn, soybean, rice, and wheat production and area by agroclimatic zone

Sources: Developed by the authors using data from FAO and Sebastian (2006).

area under corn. This implies that corn yields in temperate zones are much higher on average than corn yields in tropical and subtropical areas, which accounted for 57% of the global area in corn but produced only 34% of the world's corn output. The temperate area and output shares for global soybean production were more evenly split, at 51% and 56% respectively, implying a comparatively small variation in average soybean yields in tropical versus temperate areas.[17]

A comparison of the data represented in Panels b and c is revealing. As one might expect, less than 40% of the lower-income country areas planted to all four crops were located in temperate zones, and only 8% of the rice area is classified as temperate (Panel b). In contrast, most of the corn, soybean, and wheat cropped area in the upper-income countries was in temperate zones, although there was a significant share (65%) of rice acreage located in tropical and subtropical landscapes (Panel c). Even with this rather coarse representation of agroclimatic patterns of production, it is evident that the agroclimatic landscape of agriculture is substantially more heterogeneous in lower-income countries than it is in higher-income countries.

Comparison of the area shares with output shares reveals that all four commodities have higher yields in temperate areas than in tropical areas in both upper- and lower-income countries. This indicates that at least some of the productivity disparity between upper- and lower-income countries is driven by agroecology. As a result, inter-regional comparisons of partial productivity metrics are often implicitly qualified by assumptions about the comparability of agroecologies across regions. Further, the ever-changing spatial footprint of agricultural production requires that inter-temporal comparisons—even within the same country or region—be subject to similar caveats.

5. CONCLUSION

Subtle but substantial forces shape the spatial landscape of global agriculture. The comparative stability of total harvested area for many crops (and, notably, the cereals) worldwide over the latter half of the twentieth century belies the significant spatial relocation in crop production. Our analysis shows that global agriculture is spatially mobile, both over the long run stretching back several

[17]Global soybean production is highly concentrated in just a few countries. In 2007, Brazil, Argentina, China, and the United States collectively accounted for 88% of world soybean production, and 80% of area.

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.

The sizeable shifts in the spatial structure of agriculture revealed by our analysis adds substantial complexity to understanding the fundamental forces that affect changes in past (and potential future) agricultural productivity. This is particularly so when the location of crop production shifts over time and among agroecologies both within and among countries. A distinguishing attribute of agriculture is that its production processes are greatly affected by a host of natural inputs, such as sunlight, temperature, and rainfall (including daily, weekly, monthly, and yearly averages as well as variations in the intensity and incidence of these factors among and within these periods of time), day length, and wind speed. Typically these inputs go unmeasured, at least by economists trying to quantify agricultural production and productivity trends. Putting agriculture in a spatial-cum-agroecological setting, as well as tracking movements in that setting, provides for a more meaningful assessment of productivity trends, which are typically assessed at much coarser spatial scales, such as the state, country, or regional aggregates reported throughout the remainder of this book.

APPENDIX: ADDITIONAL DETAILS ON DATA SOURCES AND ANALYSIS

Many of the results presented in this chapter required extensive manipulation of the referenced datasets. The following subsections provide additional details on how the data were processed.

Calculation of Production and Area Shares

The base area and production data are from FAO. Country designations used in both periods pertain to 2008 geopolitical boundaries. Country-specific values were estimated using a decomposition procedure for states that were previously part of a statistical or national aggregation. Subnational data were obtained for Kazakhstan, Ukraine, and Russia from the U.S. Department of Agriculture, Foreign Agricultural Service (2008). Otherwise, data were estimated using the decomposition procedure for a number of countries, including those that made up the Socialist Federal Republic of Yugoslavia, the People's Democratic Republic of Ethiopia, Czechoslovakia, Serbia and Montenegro, the Belgium-Luxembourg statistical unit, and the Former Soviet Union (FSU). This decomposition allows for direct comparison of current and historical values.

Countries were aggregated into regions using a modified version of country aggregations developed by Wood-Sichra (2005). In order to render an analysis that is consistent with the remainder of the volume, the values presented in Section 2 include FSU separately. Thus, FSU production and area are netted out of both Europe and Asia.

Calculations Using Global Land-Use Data

The base data are described by Ramankutty et al. (2008) and Ramankutty and Foley (1999) and were downloaded from the SAGE Web site (www.sage.wisc.edu) in May of 2009. The pixilated land-use data in the 2000 series from Ramankutty et al. are based on an underlying set of cropland and pasture inventory data consisting of observations for 15,990 administrative (i.e., national and subnational) units worldwide, compared with information from just 348 administrative units that were used by Ramankutty and Foley to estimate crop cover for the 1700-1992 period. In addition, the pixilated data in the 2000 series are reported on a 5 arc-minute grid, which we aggregated to a 30 arc-minute grid for consistency and to facilitate processing with the pre-2000 series. These data are intended to represent "permanent croplands" (excluding shifting cultivation), which corresponds to FAO's notion of "arable lands and permanent crops." Although the SAGE authors make no claims about the conformability of their two series, we implicitly assume that the year 2000 values are a continuation of the 1700-1992 series. Given the inherent limitations of the underlying administrative data and the long period of backcasting involved to generate the 1700-1992 series, any results derived from these pixilated data should be used with caution, but we nonetheless deem them informative of likely broad-brush, long-run changes in the global landscape of agriculture.

To calculate centroids, a modified version of the HarvestChoice raster-to-country mappings from the International Rice Research Institute (2008) was used to assign the SAGE data to countries. The countries were assigned to regions using a modified version of region definitions developed by Wood-Sichra (2005). Grid cell sizes were approximated using the Haversine formula as given by Sinnott (1984) after Snyder (1987), and the center of gravity ("centroid") of each region was then calculated by weighting the product of the estimated area and the estimated portion under cropping for each cell.

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CHAPTER 3

Global Patterns of Crop Yields and Other Partial Productivity Measures and Prices

Julian M. Alston, Jason M. Beddow, and Philip G. Pardey

1. INTRODUCTION

More than 50 years ago Schultz (1953) and Griliches (1961) suggested that an interest in productivity stems from more fundamental concerns about the rate and sources of growth in output. The relative rates of growth of the supply and demand for food, feed, and fiber have far-reaching economic and social consequences, most readily observed through changes in commodity prices.[1] These issues have been in the background for some time—as food and fiber have

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[1]Economists have long been interested in analyzing commodity price trends and the sources of change in these trends. Among the earliest such studies in the U.S. literature are articles by Veblen (1892 and 1893) on (relative) wheat price trends and a 1922 article by Taylor titled "The Decline of Prices of Cereals." In his 1945 book *Agriculture in an Unstable Economy,* Schultz explored the nature and causes of commodity price variability during the first half of the twentieth century, notably in a chapter titled "The Unequal Growth of the Supply and Demand for Farm Products." Johnson (1948 and 1975) addressed similar themes, and Hathaway (1959) revisited Schultz's 1945 work. Tomek and Robinson (1977) provide a comprehensive review of the literature on agricultural prices to that point in time.

seemed abundant and other agricultural issues have dominated the media and policy debates—but the recent turbulence in food commodity markets reminded commentators and policymakers that food prices matter and that their causes deserve attention.

During the past few years we have seen soaring food and commodity prices globally and an increase in the dismal tally of hungry people in the world.[2] Driven in part by the demand for biofuels, stimulated by high and rising oil prices and government responses to them, prices of corn and soybeans also rose rapidly to historical highs (at least in nominal terms) in early 2008.[3] The rising prices of these and other staple commodities, in particular wheat and rice, were also stimulated by the growing demand for food in India and China fueled by the general economic growth that had contributed to a rundown of grain stocks over the previous several years. These factors, combined with some unfavorable weather in important wheat-producing regions in Russia and Australia, constituted the "perfect storm" that gave rise to the spike in grain prices in mid-2008.

In a reversal of the rapid rise in the beginning of the year, between July and November 2008 the price of oil fell back to around $50. Prices of food and feed grains have also fallen significantly. Consequently, and especially in view of financial and stock market events since mid-September 2008, the attention of many commentators has shifted from the food price crisis to the global financial crisis. Nevertheless, food commodity prices remain high relative to the experience of the past several decades, and concerns continue to be raised about the future prospects for food prices. In December 2007, *The Economist* magazine published a briefing note titled "Cheap No More" with the leader "Rising incomes in Asia and ethanol subsidies in America have put an end to a long era of falling food prices." This view has been echoed in a range of other media and at a host of symposia on the causes and consequences of the so-called food price crisis.

[2]In September 2008, the United Nation's Food and Agriculture Organization (FAO) released a provisional set of estimates (FAO 2008) indicating that "the number of undernourished people in 2007 increased by 75 million over and above FAO's estimate of 848 million undernourished in 2003-05, with much of this increase attributed to high food prices. This brings the number of undernourished people worldwide to 923 million in 2007, of which 907 million [are] in the developing world." More recently, FAO (2009) estimated that an additional 100 million people are now undernourished, increasing the total to over one billion.

[3]The price of Brent crude oil reached an all-time high of almost $145 per barrel in July 2008—almost twice the value in July 2007, which itself was historically high. The oil price cited here was obtained from http://www.eia.doe.gov/emeu/international/prices.html on November 16, 2008.

Most of the discussions have focused on the demand side of the story, emphasizing the role of economic growth in the fast-growing economies of Asia coupled with the new demand for biofuels, and treating the supply side as given. In this chapter we use graphical approaches in conjunction with newly compiled data to consider the nature of the long-term growth in the supply of food and its principal determinants to see what may be implied for the availability and price of food over the coming decades. Key to our understanding of these longer-run trends is to distinguish between possible structural shifts and realignments in the relative growth of global food supply and demand from transient factors that contribute to shorter-run instability in food prices. We document a global slowdown in growth of agricultural productivity and commodity yields, and thus in the long-term downward trend of real food commodity prices.[4] Before turning to the productivity evidence, we review trends in food prices throughout the twentieth century. This review helps not only to place recent commodity price spikes in a longer-run context but also to provide indirect evidence on productivity patterns and their main consequences.

2. TRENDS IN COMMODITY PRICES

Over the past 50 years and longer, the supply of food commodities has grown faster than the demand, in spite of increasing population and per capita incomes. Consequently, the real (deflated) prices of food commodities have steadily trended down. Figure 3.1 shows long-term trends in indexes of average annual U.S. prices of major food and feed commodities (rice, wheat, corn, and soybeans) for the period 1924 to 2008, with an insert to show price movements over more recent months. These U.S. price indexes can be used as indicators of world market prices of these commodities. The commodity price indexes generally move together over the long term, but with significant differences over shorter periods, especially for rice.

These indexes all start at 100 in the base year of 1924. After a great deal of movement over the next 45 years, by the late 1960s the prices of wheat, soybeans, and corn had roughly returned to a nominal value of 100, but the rice

[4]In making this assessment we drew on a range of evidence and used the graphical techniques recommended by Waugh, who wrote, “Fancy, super-refined mathematics and electronic computations are wonderful things, but they are of little practical use unless they describe relationships that actually exist in the real world. One of the main ways to find out about these relationships is through graphics” (1966, p. 1). Evident structural changes, especially in the price and crop yield series, limit the applicability of formal econometric approaches to analyzing these trends.

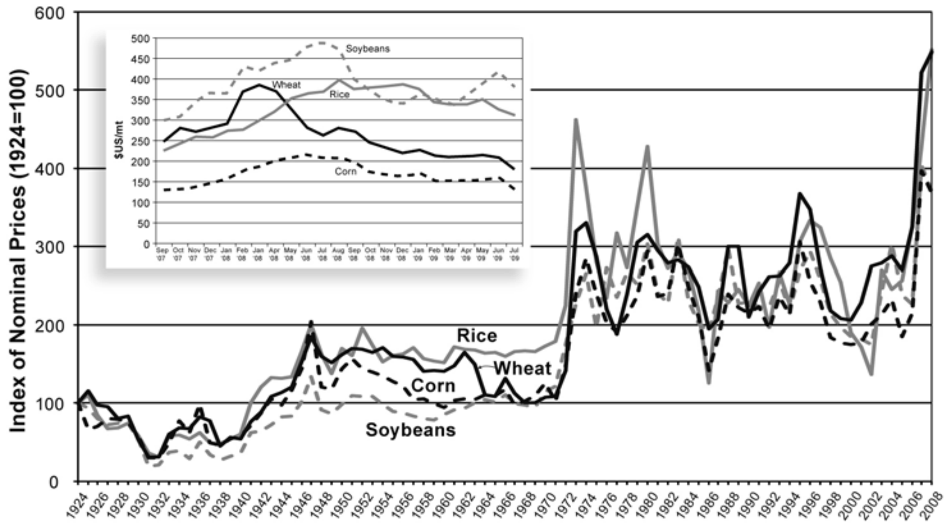

Figure 3.1. Nominal U.S. prices of corn, rice, soybeans, and wheat, 1924-2008

Sources: Compiled by the authors with data from Olmstead and Rhode 2006, FAOSTAT Database and USDA-NASS Agricultural Prices.
Notes: Data in the body of the graph represent annual averages of prices paid to farmers. Inset data are corresponding monthly average prices.

price remained much higher. The intervening years included a period of a general downward trend during the 1920s and through the early 1930s (including the effects of the Great Depression), and some rapid growth during the latter 1930s and early 1940s (including the effects of World War II), after which the prices fluctuated around a relatively flat trend. The commodity price spike in the early 1970s brought about a distinct shift in the pattern.[5] Following that price spike, the trends were again essentially flat in nominal terms but at a higher level than before 1970 (perhaps slightly trending down) until the recent price spike. Since 1975 the prices of all four commodities have tended to move together more closely than in the previous decades.

Figure 3.2 shows the price indexes for wheat, corn, and soybeans over the period 1924 to 2008, expressed in real terms by deflating by the index of prices paid by farmers. (Rice was omitted to improve the clarity of the plots. The rice prices follow a similar overall pattern to the commodity prices shown here.)

[5]Eckstein and Heien (1978) examined the food price inflation of 1973 and concluded that, in approximate rank order of importance, the causes were domestic monetary policy, government acreage restrictions, the Soviet grain deal, world economic conditions, devaluation of the dollar, and price control policies. Our emphasis in this chapter is on the long-term trends rather than the short-term deviations from these trends.

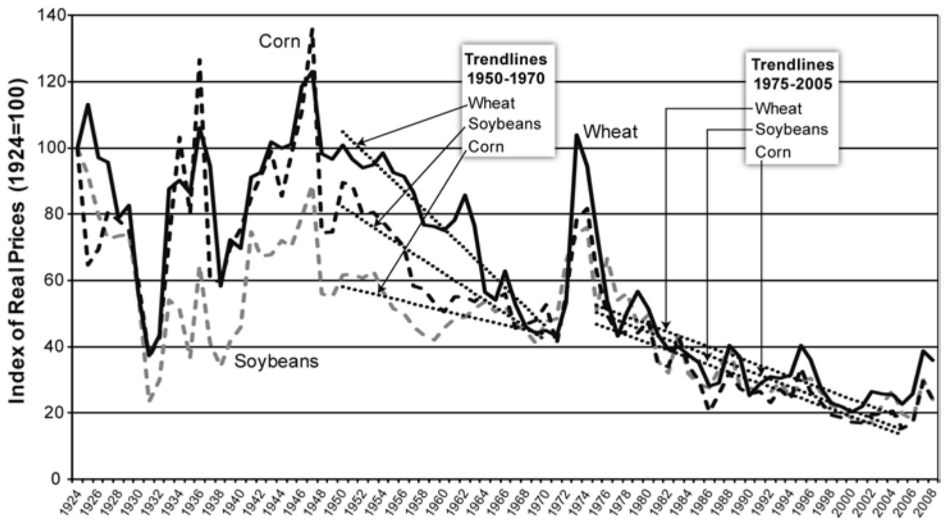

Figure 3.2. Real U.S. prices of corn, soybeans, and wheat, 1924-2008

Sources: Compiled by the authors with data from Olmstead and Rhode 2006, FAOSTAT Database and USDA 2009b.
Notes: Nominal prices were deflated using an index of farm input prices. Trend lines represent lines of OLS best fit where the respective commodity price was regressed against a linear time trend during each period.

The deflated series provides some perspective on the latest price spike, in which commodity prices roughly doubled in real terms compared with the 1970s and mid-1930s when they more than doubled. Moreover, at their recent peak, real commodity prices fell well short of the prices that prevailed during the previous price spikes. In the case of corn, for example, in real terms the peak price in June 2008 was 50% below the peak price in 1974, 66% below the peak price in 1936, and nearly 80% below the peak price in 1947. Questions remain about whether the general path of the previous price trend will be restored.

The longer trends are of interest, too. In real terms, commodity prices trended up generally (albeit with some major fluctuations during and after the Great Depression) from 1929 through the end of World War II, after which they have trended generally down. This downward trend was interrupted by the major price spike in the 1970s and again at the end of the series by the latest price spike. The trend lines in the figure show the real prices declining at different rates during the period 1950-1970, as they converged toward equality. Then following the 1970s price spike, over the period 1975-2005, they trended down at roughly equal rates.

Table 3.1 includes measures of rates of change in real and nominal prices of the four commodities over the entire period and several subperiods. The long-term trend in deflated prices has been remarkable. Over the 55 years between 1950 and 2005, in real terms rice prices fell at an average annual rate of 2.9%. On average, wheat prices declined by 2.7% per year, soybean prices by 2.1% per year, and corn prices by 3.2% per year. After the jump in the early 1970s, over the 30 years between 1975 and 2005, in real terms rice prices fell at an average rate of 4.1% per year, wheat prices by 4.0% per year, soybean prices by 3.2% per year, and corn prices by 4.7% per year. These changes in prices of staple commodities are cumulative, enduring, and economically im-

Table 3.1. Average annual percentage changes (% per year) in U.S. commodity prices, 1866-2008

	Commodity			
Period	**Corn**	**Wheat**	**Rice**	**Soybeans**
Nominal Prices				
1866-2008	1.25	0.84	n.a.	n.a.
1924-2008	1.55	2.03	2.03	1.56
1950-2005	0.46	0.94	0.74	1.60
1950-1970	-0.67	-2.04	0.08	0.72
1975-2005	-0.87	-0.20	-0.29	0.64
1990-2005	-1.02	1.66	0.90	0.25
2000-2005	1.07	5.38	6.03	5.07
1950-2008	1.62	2.11	2.03	2.28
1975-2008	1.30	1.97	2.06	1.91
1975-1990	-0.72	-2.05	-1.47	1.03
1990-2008	2.98	5.32	5.01	2.65
2000-2008	9.29	12.22	13.35	8.66
Deflated Prices				
1924-2008	-1.70	-1.22	-1.22	-1.69
1950-2005	-3.20	-2.72	-2.91	-2.05
1950-1970	-2.67	-4.04	-1.92	-1.29
1975-2005	-4.66	-3.99	-4.08	-3.15
1990-2005	-3.43	-0.75	-1.51	-2.16
2000-2005	-2.30	2.01	2.66	1.70
1950-2008	-2.27	-1.79	-1.87	-1.62
1975-2008	-2.90	-2.23	-2.14	-2.29
1975-1990	-5.89	-7.22	-6.64	-4.15
1990-2008	-0.41	1.93	1.62	-0.74
2000-2008	4.09	7.01	8.15	3.45

Sources: Calculated by the authors based on data compiled from Olmstead and Rhode 2006, FAOSTAT Database and USDA 2008b.
Note: Deflated prices were computed by deflating nominal commodity prices by an index of farm input prices.

portant.[6] For comparison, Table 3.1 also includes price trends for the periods ending 2008, which includes the price increases that started in about 2006. The long-run trend of declining real prices since 1975 is muted by the recent price increases but not reversed.

It is useful to split the period 1975-2005 into two subperiods, before and after 1990. This break point was identified in previous work by Alston et al. (2010) looking at U.S. productivity patterns. For all four commodities the real rate of decline of prices was substantially slower over the period 1990-2005 than for the previous period 1975-1990 and for the 30-year period 1975-2005. This slowdown of the rate of price decline was more pronounced for the food grains, wheat and rice, than for the feed commodities, corn and soybeans, consistent with a faster rate of productivity growth in the feed commodities that have disproportionately benefited from private research by biotech firms and seed companies. Toward the end of the period, but still before the onset of the recent price spike that became evident after 2005, the rate of decline of real prices slowed even more—in fact, between 2000 and 2005, prices increased in real terms for rice, soybeans, and wheat. Prices increased markedly for all four commodities after 2005, including the recent price spike.

In summary, the period since World War II includes three distinct subperiods. First, over the 20-year-period 1950-1970, prices for rice, corn, and soybeans declined relatively slowly, while wheat prices declined fairly rapidly. Next, following the price spike of the early 1970s, over the years 1975-1990, real prices for all four commodities declined relatively rapidly. Finally, over the years 1990-2005, the rate of price decline slowed for all four commodities, especially toward the end of that period. The question yet to be resolved is whether, in general, we have entered a new era in which real commodity prices will no longer be falling rapidly or even a new era of rising real commodity prices.

Figure 3.3 shows some comparable price indexes for field crops, specialty crops, and livestock products over the period 1949-2004 for which detailed index numbers are available from the work of Alston et al. (2010). Panel a shows the nominal indexes. The prices of specialty crops have grown both absolutely and

[6]As Hulten (1986) and Roeger (1995) illustrate, under certain conditions, the rate of decline of an output-input price ratio such as the deflated commodity price series presented here corresponds to a dual measure of the rate of multifactor productivity growth, and so the declines in these deflated price trends reflect substantial and rapid productivity growth. The correspondence is closer if the deflator corresponds more closely to the appropriate price index for the inputs used to produce the output. Deflating by the implicit GDP deflator or the consumer price index rather than the index of prices paid by farmers for inputs in practice results in generally similar patterns of change overall in the real price trends for each commodity (but with differences in some of the details).

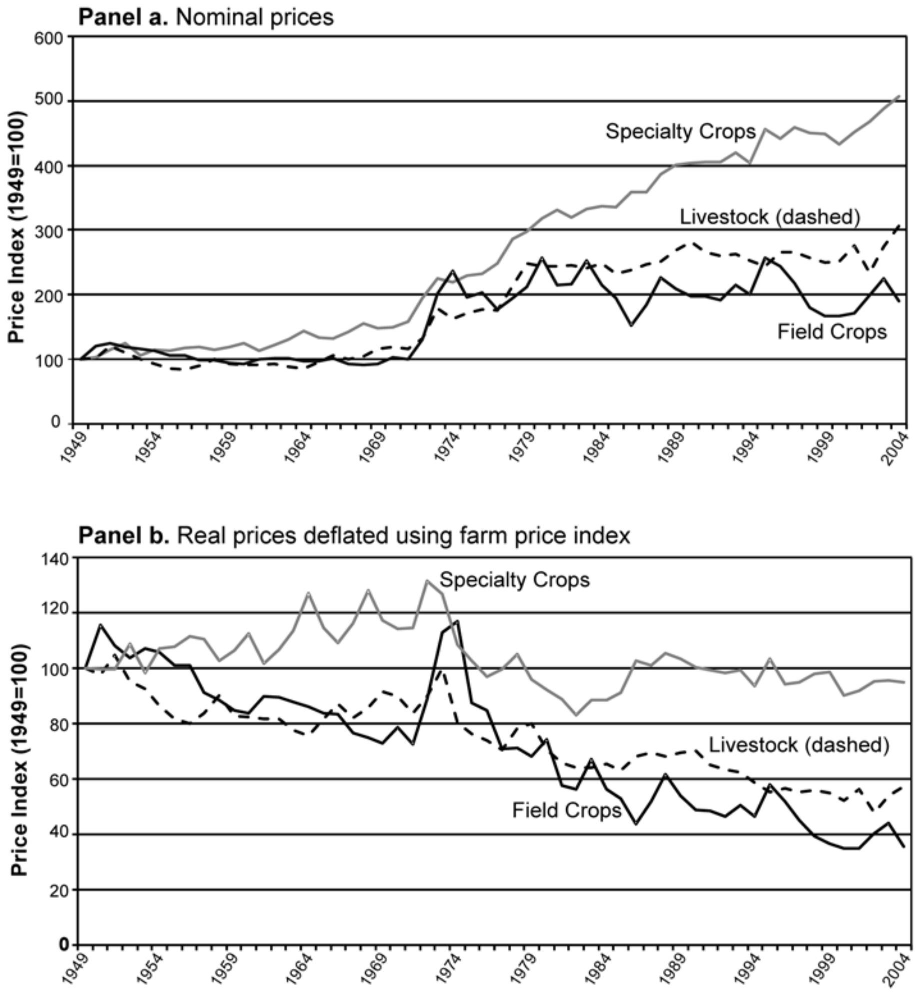

Figure 3.3. U.S. prices of specialty crops, field crops, and livestock, 1949-2004
Source: Adapted from Alston and Pardey 2008.

relative to field crops and livestock products, which have had fairly static nominal prices for the 20 years prior to 2004 in spite of general input price inflation. As discussed by Alston, Sumner, and Vosti (2006), some of the price increases for specialty crops might reflect premia for changes in quality, variety, or seasonal availability that were not fully addressed in the indexing procedure. Figure 3.3, Panel b, shows the same price series deflated by an index of prices paid by farmers for inputs. Real prices received by farmers for all crop categories trended down, but at different rates. Over the period 1949-2004, in real terms prices for field crops fell by 64.5%, prices for livestock fell by 42.7%, and prices for specialty crops fell by 5.3% (8.6% for vegetables, 3.0% for fruits and nuts, and 0.2% for nursery and greenhouse).

These price trends reflect the fact that global supply has been growing faster than global demand, and that supply and demand have been growing at different rates for the different categories of products. Here we are focusing on the supply side. Growth in supply reflects the increased use of some inputs, especially increases in land, water, and chemical inputs (including fuels, fertilizers, and pesticides). This is balanced partly by labor savings in many places, combined with increases in productivity of inputs. Major increases in productivity and changes in input combinations around the world and over time have been associated with changes in technology, along with other changes that contributed to enhanced efficiency of production.

3. U.S. AND GLOBAL YIELD TRENDS

Table 3.2 includes growth rates of yields for selected U.S. crops, including corn, wheat, rice, and soybeans for various time periods. The yield growth accelerated in the second half of the twentieth century relative to the first half. But for corn, rice, and wheat (and to a lesser extent for soybeans), average annual rates of yield growth were much lower in 1990-2008 than in 1950-1990. These U.S. yield patterns are consistent with the price patterns discussed previously, but of course prices depend on global supply and demand, not just U.S. yields.[7]

Table 3.2. Rates of growth (% per year) of yield for selected U.S. crops, 1866-2008

	Crop Yields			
Period	Corn	Wheat	Rice	Soybeans
1866-2008[a]	1.30	0.99	1.58	n.a.
1900-2008[a]	1.57	1.21	1.50	1.52
1900-1950[a]	0.61	0.60	1.33	2.61
1950-2008	2.40	1.73	1.86	1.04
1950-1990	2.83	2.18	2.12	1.13
1990-2008	1.45	0.71	1.19	0.83

Sources: Calculated by the authors based on data reported in Beddow, Hurley, and Pardey 2009 derived from Alston and Pardey 2006 and USDA-FAS unpublished data.
[a] Rice yields start in 1895, soybeans in 1924.

[7]See Chapter 8 in this volume for more detail on U.S. yield growth and developments generally regarding agricultural productivity growth in the United States. Alston et al. (2010, Chapter 5) provide even more detail on U.S. agricultural productivity patterns and examine the slowdown in crop yields in terms of both the absolute and proportional growth in yields.

Figure 3.4 plots average global yields for corn, rice, and wheat (in metric tons per harvested hectare) since 1961 (the earliest year for which global yield estimates are reported by the United Nations' Food and Agriculture Organization [FAO], whence most of these data were drawn). 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. Corresponding annual average rates of yield growth are reported in Table 3.3. Separate estimates of average growth rates of yields are reported for North America, Western Europe, and Eastern Europe, for high-, middle- and low-income countries, and for the world as a whole, for two subperiods: 1961-1990 and 1990-2007.[8] The slowdown evident for the global averages (Table 3.3) mirrors the slowdown in U.S. crop yield growth (in Table 3.2), although the low-income countries have seen increasing rates of growth in wheat and rice yields.

For all four commodities, in both high- and middle-income countries, average annual rates of yield growth were lower in 1990-2007 than in 1961-1990. The growth of wheat yields slowed the most and, for the high-income countries as a group, wheat yields barely changed over the 1990-2007 period.

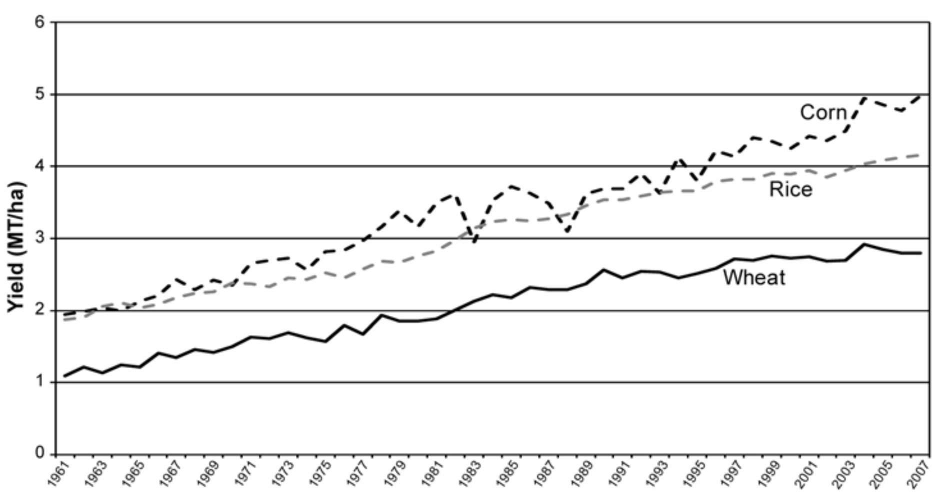

Figure 3.4. Average global yields for selected crops, 1961-2007
Source: Compiled by the authors from FAOSTAT Database.

[8]Low-income countries are those with a per capita gross national income (GNI) of $975 or less, high-income countries are those with a per capita GNI greater than $11,905, and middle-income countries are those with a per capita GNI that falls between these values (World Development Indicators Database).

Table 3.3. Global yield growth rates (% per year) for selected crops, 1961-2007

	Corn		Wheat		Rice		Soybeans	
Group	**1961-1990**	**1990-2007**	**1961-1990**	**1990-2007**	**1961-1990**	**1990-2007**	**1961-1990**	**1990-2007**
World	2.20	1.77	2.95	0.52	2.19	0.96	1.79	1.08
N. America	2.20	1.40	2.23	0.01	1.67	1.54	1.05	0.04
W. Europe	3.30	1.81	3.31	0.63	0.38	0.55	1.64	0.05
E. Europe	1.91	0.97	3.18	-1.69	-0.41	1.07	1.90	2.29
Per capita income								
High	2.34	1.48	2.47	0.06	1.07	0.54	1.14	0.02
Middle	2.41	2.12	3.23	0.85	2.54	0.81	3.21	2.08
Low	1.07	0.65	1.32	2.15	1.46	2.16	2.63	0.00

Sources: Authors' calculations based on FAOSTAT Database and USDA-FAS unpublished data.

Global corn yields grew during 1990-2007 at an average rate of 1.77% per year compared with 2.20% per year for 1961-1990. Likewise, rice yields grew at less than 1.0% per year after 1990, less than half their average growth rate for the period ending 1990. Again, paralleling productivity developments in the United States, the slowdown in crop yields is quite pervasive. In more than half of the countries growing these crops, yields for rice, wheat, corn, and soybeans grew more slowly during 1990-2007 than during 1961-1990 (Table 3.4). More critically, among the most important producers (i.e., the top 10 producing countries worldwide) the slowdown was generally more widespread than among all producing countries.

The interpretation of average global crop yields is problematic for several reasons. For one, countries located in tropical and temperate regions of the world differ considerably in terms of their propensity to plant multiple crops per year, and cropping intensities have changed considerably over time for certain regions of the world.[9] The yield data used here (and by most other observers) report

[9]Wood, Sebastian, and Scherr (2000) developed measures of cropping intensities worldwide that expressed the annual harvested area as a proportion of total crop land (including land in use and fallowed land). Swidden agriculture, for example, relies on maintaining a significant share of production in fallow every year (thus having a cropping intensity of less than one) whereas some irrigated areas in the tropics can produce up to three crops a year from the same physical area (thus having a cropping intensity of three). In 1997, the global average annual cropping intensity was estimated to be about 0.8 (Wood, Sebastian, and Scherr 2000, p. 23). In South Asia, with its extensive use of irrigation, the average intensity was 1.1, whereas in Western Europe and North America the intensities were between 0.6 and 0.7.

Table 3.4. Percentage (%) of countries with slower yield growth since 1990

Grouping	Corn	Wheat	Rice	Soybeans
All countries	56	78	56	65
Top 10 producers	60	100	60	78
Top 25 producers	60	88	48	71

Sources: Authors' calculations based on FAOSTAT Database and USDA-FAS unpublished data.
Notes: 155 countries are included for corn, 114 for wheat, 108 for rice, and 55 for soybeans. Only countries with area and production data for both periods are included.

yields on the basis of harvested area, which will count the same land twice if it is cropped twice in a given calendar year. An alternative is to report yields on the basis of arable area, which will count the land area only once per year regardless of how often it is cropped. Reporting yields on the basis of harvested area would understate the rate of growth in crop yields compared with crop yields measured on the basis of arable area if the intensity of crop plantings per year had increased over time.[10]

Another confounding factor when interpreting changes in global or regional yield aggregates (as well as national aggregate yields for that matter) is the effects of the changing spatial location of production (see also Chapter 2 of this volume). Table 3.5 illustrates that the location of worldwide wheat production, for example, has moved markedly, even since the early 1960s. During the three-year period 1961-1963, Russia accounted for 15% of the world's wheat production (35.4 million metric tons) and ranked first among wheat producers worldwide. By 2005-2007, Russia had slipped to the world's fourth-ranked wheat producer, accounting for 7.8% (47.4 million metric tons) of world wheat production during those years. The massive increases in production by India and, especially, China are particularly evident in Table 3.5. These changes in location of production imply changes in average productivity (yields) to the extent that different locations have different endowments of soils and climate, different incentives, and different technological opportunities.[11]

[10]For example, if rice yields averaged 2 tons per harvested hectare in 1961 and doubled to 4 tons per harvested hectare by 2007, that would be equivalent to an average annual yield growth of 1.5% per harvested hectare per year. In contrast, if yields per harvested area doubled from 2 to 4 tons per hectare from 1961 to 2007 while the cropping intensity also increased from one to two crops per calendar year, yields reported on the basis of arable area would have grown from 2 to 8 tons per arable hectare, or 3.1% per year.

[11]Olmstead and Rhode (2002) discuss and document this phenomenon in the context of the early development of the U.S. wheat industry.

Table 3.5. Changing spatial location of global wheat production, 1961-63 and 2005-07

1961-1963				2005-2007			
Rank	Country	Production (mmt)	Share (%)	Rank	Country	Production (mmt)	Share (%)
1	Russia	35.4	15.0	1	China	103.9	17.0
2	U.S.	31.5	13.4	2	India	71.0	11.6
3	China	16.5	7.0	3	U.S.	53.4	8.7
4	Canada	14.3	6.0	4	Russia	47.4	7.8
5	France	11.3	4.8	5	France	35.2	5.8
Top 5 Total		109.0	46.3	Top 5 Total		310.8	50.9
6	India	11.3	4.8	6	Canada	23.9	3.9
7	Ukraine	10.5	4.5	7	Germany	22.5	3.7
8	Kazakhstan	9.9	4.2	8	Pakistan	22.1	3.6
9	Italy	8.6	3.7	9	Turkey	19.7	3.2
10	Turkey	8.6	3.7	10	Australia	16.3	2.7
Top 10 Total		157.9	67.1	Top 10 Total		415.4	68.0
Top 20 Total		201.8	85.7	Top 20 Total		521.9	85.5

Source: Authors' calculations based on FAOSTAT Database and USDA-FAS unpublished data.
Notes: The country designations used in both periods pertain to 2008 geopolitical boundaries. For states that were previously part of a statistical or national aggregation, country-specific values were estimated using a decomposition procedure when reliable subnational area and production data were unavailable. Subnational data were obtained for Kazakhstan, Ukraine, and Russia. Otherwise, data for a number of countries were estimated using the decomposition procedure, including those of the Socialist Federal Republic of Yugoslavia, the People's Democratic Republic of Ethiopia, Czechoslovakia, Serbia and Montenegro, the Belgium-Luxembourg aggregation, and the Former Soviet Union.

4. LAND AND LABOR PRODUCTIVITY

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 1.2% per year growth) 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 foregoing global crop yield evidence, the longer-run growth in land and labor productivity masks a widespread slowdown in the rate of growth of both productivity measures during the post-1989 period compared with the previous three decades. Among the world's top 20 producers (according to their 2005 value of agricultural output), land and labor productivity growth in the period 1990-2005 was significantly slower than in 1961-1990, once the large, and in many respects exceptional, case of China is set aside (Table 3.6). Across the rest of the world (i.e., after setting aside the top 20 producing countries), on average, the slowdown is even more pronounced.

Table 3.6. Growth in agricultural land and labor productivity worldwide, 1961-2005

	Land Productivity		Labor Productivity	
Group	**1961-90**	**1990-05**	**1961-90**	**1990-05**
World	2.03	1.82	1.12	1.36
Excl. China	1.90	1.19	1.21	0.42
Excl. China & FSU	1.91	1.57	1.13	0.73
Latin America	2.17	2.83	2.15	3.53
Asia	2.56	3.01	1.83	2.72
Excl. China	2.45	1.83	1.69	1.24
China	2.81	4.50	2.29	4.45
Africa	2.18	2.21	0.68	0.90
Low-Income Countries	2.00	2.39	0.46	1.03
Middle-Income Countries	2.35	2.30	1.51	2.02
Excl. China	2.18	1.37	0.39	0.81
High-Income Countries	1.61	0.72	4.26	4.18
Top 20 Producers	2.11	2.16	1.17	1.77
Excl. China	1.98	1.38	1.33	0.63
Other Producers	1.74	0.88	1.00	0.07

Sources: Authors' calculations based on FAOSTAT Database and USDA-FAS unpublished data.
Notes: Labor is measured as economically active workers in agriculture. Land is the sum of area harvested and permanently pastured areas. Output is a value of production measure developed by the authors by weighting a time series of country-specific commodity quantities (spanning 155 crop-related and 30 livestock-related commodities) with an unpublished 1999-2001 global average of commodity-specific international prices developed by FAO.

For this group of countries land productivity grew by 1.83% per year during the period 1961-1990 but by only 0.88% per year thereafter; labor productivity grew by 1.08% per year prior to 1990, but barely budged during the period 1990-2005.

Worldwide, land productivity grew at a slower pace in the period 1990-2005 (1.82% per year) than during earlier decades (2.03% per year), whereas labor productivity increased at a faster rate for the period 1990-2005 than for 1961-1990 (1.37% versus 1.12% per year). Once again these world totals are distorted by the significant and exceptional case of China. Netting out China, global land and labor productivity growth has been slower in the period 1990-2005 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 (net of China and FSU) productivity slowdown is less pronounced because both partial productivity measures for the FSU actually shrank during the period 1990-2005.[12]

Figure 3.5 draws on the FAOSTAT database to report land and labor productivity measures for 212 countries (some of which no longer exist) grouped into various aggregates according to regions and per capita income. Here we use the graphical technique developed by Hayami and Ruttan (1971), where the horizontal axis measures labor productivity (in logarithms) and the vertical axis measures land productivity (in logarithms). The productivity loci were formed by taking ratios of the value of aggregate output to the quantity of land input and to the quantity of labor input. Output is an estimate of the total value of agricultural output (spanning 155 plant commodities and 30 animal commodities) expressed in 1999-2001 average purchasing power parity agricultural prices obtained from FAO. Land is a measure of harvested and permanently pastured area, and labor is a head count of the economically active workers in agriculture. These ratios were then scaled by the corresponding value ratios of output and input in the base year 1961, and the natural logarithms of the scaled index ratios were then taken. Since both axes are mea-

[12]While notable in their own right and of significance in terms of global totals, developments in the FSU and China are exceptional, with unique, essentially one-off attributes. The impacts on agricultural productivity growth and downsizing of agriculture in the FSU economies following the break-up of the Soviet Union are documented and discussed by Mathijs and Swinnen (1998), Macours and Swinnen (2002), and Brooks and Gardner (2004) among others. The massive institutional changes in China (notably the introduction of the household responsibility system into Chinese agriculture in the late 1970s) also had a sizable, one-shot, albeit enduring, effect on productivity developments in that country (see for example, Lin 1992 and Fan and Pardey 1997).

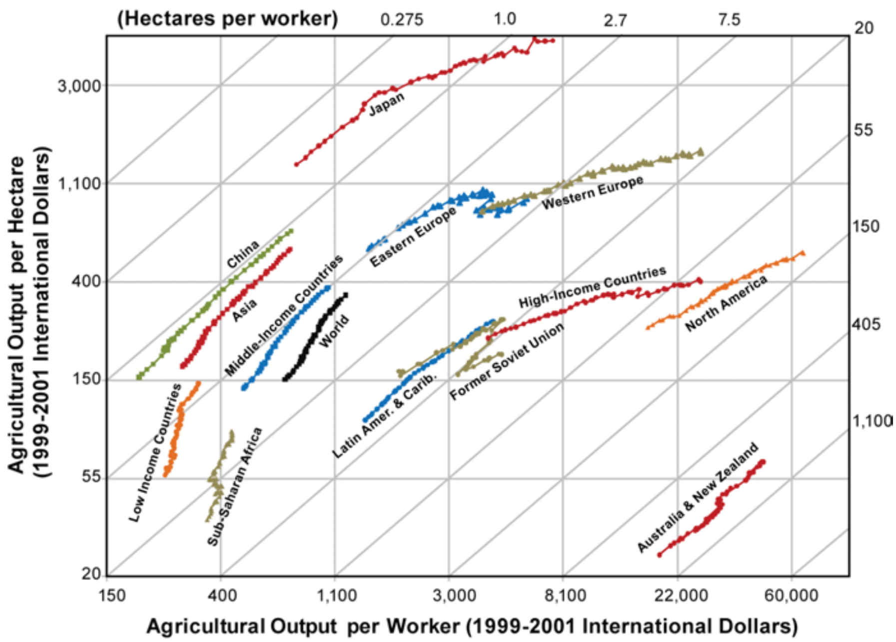

Figure 3.5. Land and labor productivity by region, 1961-2005

Sources: Authors' calculations based on FAOSTAT Database and USDA-FAS unpublished data.
Notes: The land-labor ratio is constant along each grey diagonal line, and values for those ratios are given at the terminus of the respective diagonal line on the top and right axes. Notably, any arbitrary 45 degree line represents a constant land-labor ratio, so regional plots with slopes greater than 45 degrees (e.g., Sub-Saharan Africa and the middle-income countries) indicates increased land use relative to labor use while the opposite is true for regions with plots that have a slope of less than 45 degrees (e.g., North America and Western Europe).

sured in natural logarithms, a unit increase in either direction is interpreted as a proportional increase in land or labor productivity, and the length of the productivity locus is an indication of the average annual rate of change in productivity. All of the productivity paths move generally (but not uniformly) in a northeasterly direction, starting in 1961 and ending in 2005, indicating productivity growth.

The diagonals indicate constant land-to-labor ratios. As the productivity locus for a particular country or region crosses a diagonal from left to right, it indicates a decrease in the number of economically active workers in agriculture per harvested hectare in that region. Substantive but gradually changing differences can be seen in the land-labor ratios among countries and regions. In Japan's case, land-labor ratios rose from 0.6 hectares per worker in 1961 to 1.6 in 2005. Land-labor ratios in Australia and New Zealand have changed little, whereas they have risen by some 83% in North America. They also rose, albeit very slowly, for the Latin America and Caribbean region, consistent with the region's labor productivity growing slightly faster than its land productivity. Sub-Saharan Africa has become much more labor-intensive so its land-labor ratios have declined. In 1961 the region averaged 10.0 hectares per agricultural worker, but by 2005 the land-labor ratio had halved to 5.0 hectares per worker.

The relative positions of the productivity loci are revealing as well. In the terminal year of the data series, 2005, low-income countries as a group averaged just $331 of output per agricultural worker, compared with $1,032 per worker for middle-income counties and $26,975 per worker for high-income counties when taken as a group. The land productivity relativities are less clearly tied to per capita incomes. For example, middle-income countries as a group had similar output per hectare in 2005 ($381) as the high-income countries ($405 per hectare). According to these data, in 2005 the average land productivity in sub-Saharan Africa ($88 per hectare) exceeded that of Australia and New Zealand ($64 per hectare). Clearly, broad, regional productivity trends mask significant local variation caused by a host of agro-ecological, market-related, and policy-related factors.

5. INTERPRETATION AND INFERENCES

Much of the dramatic transformation of global agriculture over the past 100 years, as well as before that, can be traced to the adoption of new technologies that allowed more to be produced with less. The increases in agricultural productivity have been impressive and enormously valuable. It can be difficult to partition the past productivity growth accurately between elements associated with new technology and elements attributable to other sources (including weather and infrastructure), but technological change has surely been the main source. Technological change itself can come from multiple sources, but organized research undertaken by governments and industry has played a central role, especially over the past 150 years.

In this chapter we have presented a range of different measures of productivity across many countries, and the counterpart patterns of commodity prices. This evidence consistently indicates that the long-term downward trends in real prices of food and feed commodities, like their counterpart measures of partial and multifactor productivity, accelerated in the 1970s and 1980s and then slowed in the 1990s and the first half-decade of the twenty-first century. Such patterns are difficult to discern precisely given the effects of temporary fluctuations associated with year-to-year variations in weather, and more-enduring but still temporary departures from trend, such as the price spike in the early 1970s. Additionally, measured growth rates are sensitive to the choices of starting and ending dates, and more so when the intervals are shorter.

The compilation of country-specific studies reported in Alston et al. (2000) reveals a strong association between lagged research and development (R&D) spending and agricultural productivity improvements. We suspect that a substantial share of past agricultural productivity growth resulted from agricultural R&D. Consistent with that view, and the fact that research affects agricultural productivity with a long lag, we also suspect that the reduced growth in productivity observed during the past decade or two may be attributable in significant part to a slowdown in the rate of growth in spending on agricultural R&D a decade or two previously.[13]

An implication of our analysis is that a restoration of the growth in spending on agricultural R&D may be necessary to prevent a longer-term food price crisis of a more enduring nature. This message may be discounted or dismissed on the grounds that, if necessary, science can solve this problem, as it did in the 1970s, proving false the prophecy of the doomsayers of the time such as the "Club of Rome."[14] Optimism about the potential for science to contribute to solving our problems may well be justified, but an appropriate investment in science and the translation of that scientific know-how into technological changes on farms is required to realize that potential—it should not be forgotten that the 1960s and 1970s witnessed a very rapid growth in spending on agricultural science around the world, including the creation of the Consultative Group on International

[13]See also von Braun 2007 and Trostle 2008.

[14]For example, in *The Population Bomb*, published in 1968, the eminent ecologist Paul Ehrlich predicted that in the 1970s "the world will undergo famines—hundreds of millions of people are going to starve to death in spite of any crash programs embarked upon now. At this late date nothing can prevent a substantial increase in the world death rate…." (p. 11). William and Paul Paddock's 1967 *Famine 1975! America's Decision: Who Will Survive?* had a similar message. They advocated a triage approach to foreign aid, in which countries in need of food aid should be divided into three groups, as are soldiers injured in battle. The "can't be saved" group, which should receive no aid, included India and the Philippines, both of which have since had years of food surplus from their own harvests. Biologist Garrett Hardin, famous for coining the phrase "The Tragedy of the Commons" to describe the very real problems that can arise when there is open access to exploitation of a natural resource, published *The Limits of Altruism* in 1977 in support of a "tough-minded" approach that recognized that countries like India had exceeded their "carrying" capacity.

Agricultural Research, which played an instrumental role in the green revolution (Alston, Dehmer, and Pardey 2006).

Some may suggest that we can count on the private sector to solve the problem. Indeed, seed and biotech firms have a range of technologies in prospect if not already in the pipeline. For instance, speaking at the U.S. Department of Agriculture's Agricultural Outlook Forum in February 2008, DuPont Vice President and General Manager and Pioneer Hi-Bred President Paul Schickler said, "We expect the traits and technologies in our product pipeline to help meet that demand by doubling the rate of genetic gain—targeting a 40% yield increase in our corn and soybean products over the next 10 years." More recently, in an article in the *New York Times* in June 2008, Andrew Pollack reported that "Monsanto, the leader in agricultural biotechnology, pledged Wednesday to develop seeds that would double the yields of corn, soybeans, and cotton by 2030 and would require 30% less water, land, and energy to grow."[15]

Such prospects might provide grounds for optimism about the potential of agricultural supply to more than keep pace with demand. But even if the technology possibilities can be realized (and adopted in some parts of the world), there are big differences between what is possible in the laboratory and what happens in farmers' fields. We have to remember that the regulatory approval process is long and expensive and getting longer and more expensive for new biotech crop varieties, so the rates of innovation will be slower in farmers' fields than in the laboratories. And it is still the case that much of the world has not begun to adopt biotech varieties because of perceived market resistance or other political barriers, so the benefits from any rapid yield gains in biotech crop varieties will accrue only on a fraction of farmers' fields around the world.

Relative to past performance, the claims by Monsanto and DuPont about potential yield gains seem very optimistic. The rates of yield gain realized in farmers' fields would have to match the highest ever, as recorded in the 1960s and 1970s, and recent yield growth rates have not been nearly so fast. Both claims imply a sustained compound growth rate of about 3.4% per year, a rarity in recent history. Figure 3.6 identifies the number of years for which corn yield growth averaged 3.4% per year over the previous decade. This occurred

[15]The Schickler quote is available at http://www.pioneer.com/web/site/portal/menuitem.d4f86eb536a8ca24c5892701d10093a0/ and the Pollack article is at http://www.nytimes.com/2008/06/05/business/worldbusiness/05crop.html?pagewanted=print.

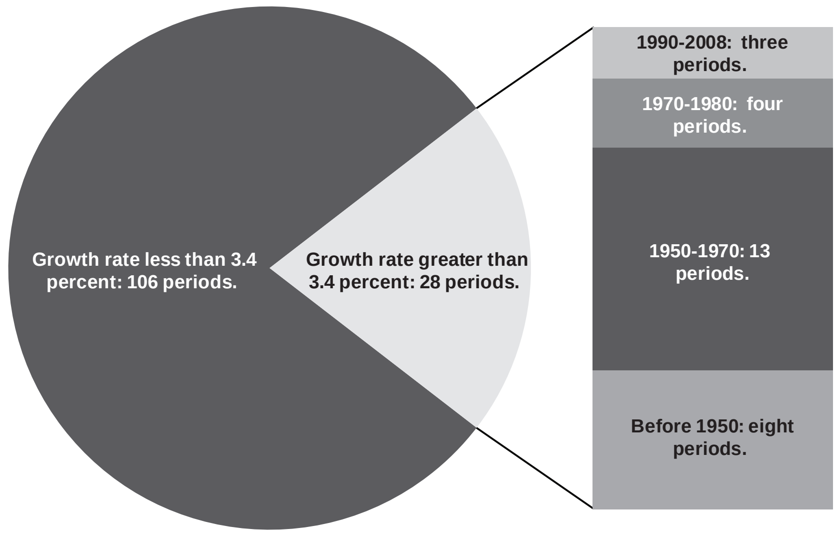

Figure 3.6. Number of 10-year periods since 1875 when growth in corn yields exceeded 3.4% per year
Sources: Authors' calculations based on data reported in Beddow, Hurley and Pardey 2009, derived from Alston and Pardey 2006 and QuickStats: Agricultural Statistics Database.
Note: Values are attributed to the end of each 10-year period. For example, the 1950-1970 category includes all 10-year periods ending between 1950 and 1969 (thus starting between 1941 and 1960).

in only 28 instances during the past 133 years, and about half of those instances were for 10-year periods ending in the 1950s and 1960s. In contrast, only one-sixth of the years during the 1990s and since 2000 had corn yield growth rates in excess of 3.4% per year over the preceding 10 years. While it is feasible to sustain (global) growth rates that would achieve the Monsanto and Du Pont targets, it seems improbable, especially given recent trends in crop yields.[16] To do so would mean the future must be substantially different from the more recent past.

[16]The more-recent evidence further lengthens the odds of achieving a 3.4%-per-year worldwide growth rate of crop yields. World average yield growth rates exceeded that target for corn for only two decade periods ending after 1961 (i.e., the decades ending in 1973 and 1979); wheat for seven decade periods (four of which terminated in years during the 1970s); and soybeans only once. Rice yields never sustained that average rate of growth for a 10-year period. Moreover, average growth in crop yields for all fours crops never exceeded the 3.4%-per-year threshold for any decade period ending after 1990. Further, the Monsanto claim suggests that yield growth rates in excess of 3.4% per year can be sustained over a period of two decades, which, historically, even in the United States has not occurred since the decade ending in 1960.

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CHAPTER 4

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

Keith O. Fuglie

1. INTRODUCTION

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

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

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

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

To circumvent the lack of price or cost data, most previous assessments of global agricultural TFP have relied on distance function measures like the Malmquist index to compare productivity among groups of countries. Distance functions are derived from input-output relationships based on quantity data only. Recently, Ludena et al. (2007) used this method to estimate agricultural productivity growth for 116 countries and found that average annual agricultural TFP growth increased from 0.60% during 1961-1980 to 1.29% during 1981-2000. But this methodology is sensitive to the set of countries included for comparison and the number of variables in the model, or the dimensionality issue (Lusigi and Thirtle 1997). Coelli and Rao (2005) have also observed that the input shadow prices derived from the estimation of this model vary widely across countries and over time and in many cases are zero for major inputs like land and labor, which does not seem plausible.

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

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

2. MEASURING TOTAL FACTOR PRODUCTIVITY IN AGRICULTURE

2.1 Methods for TFP Measurement

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

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

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

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

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

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

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

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

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

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

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

2.2. Output and Input Data

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

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

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

For agricultural inputs, FAO publishes data on cropland (rain-fed and irrigated), permanent pasture, labor employed in agriculture, animal stocks, the number of tractors in use, and inorganic fertilizer consumption. I supplement these data with better or more up-to-date data from national or industry sources whenever available. For fertilizer consumption, the International Fertilizer Association has more up-to-date and more accurate statistics than does FAO on fertilizer consumption by country, except for small countries. For agricultural statistics on China, a relatively comprehensive dataset is available from the Economic Research Service (ERS 2009b), with original data coming from the National Bureau of Statistics of China (2006). For Brazil, I use results of the recently published 2006 Brazilian agricultural census (IPGE 2008), and for Indonesia, I compiled improved data on agricultural land and machinery use (Fuglie 2004, 2010). For Taiwan, I use statistics from the Council of Agriculture. Finally, since FAO reports data on countries that made up the former Soviet Union only from 1991 and onward, I extend the time series for each of the former Soviet Socialist Republics (SSRs) back to 1965 from Shend (1993). Also, since FAO labor force estimates for former SSRs and Eastern Europe are not reliable for the post-1991 years (Lerman et al. 2003; Swinnen, Dries, and Macours 2005), I use Eurostat data for the Baltic states and Eastern Europe, CISSTAT data for other former SSRs except Ukraine, and the International Labor Organization's LABORSTA database for Ukraine for estimates of the size of the agricultural labor force since 1990.

Inputs are divided into five categories. *Farm labor* is the total economically active adult population (males and females) in agriculture. *Agricultural land* is the area in permanent crops (perennials), annual crops, and permanent pasture. Cropland (permanent and annual crops) is further divided into rain-fed cropland and cropland equipped for irrigation. However, for agricultural cropland in Sub-Saharan Africa I use total area harvested for all crops rather than the FAO series on arable land (see Fuglie 2009 for a discussion of why this series appears to be a better measure of agricultural land in this region). I also derive a quality-adjusted measure of agricultural land that gives greater weight to irrigated cropland and less weight to permanent pasture in assessing agricultural land changes over time (see the next section on "land quality"). *Livestock* is the aggregate number of animals in "cattle equivalents" held in farm inventories and includes cattle, camels, water buffalos, horses and other equine species (asses, mules, and hinnies), small ruminants (sheep and goats), pigs, and poultry species (chickens, ducks, and turkeys), with each species weighted by its relative size. The weights for aggregation based on Hayami and Ruttan (1985, p. 450) are as follows: 1.38 for camels, 1.25 for water buffalo and horses, 1.00 for cattle and other equine species, 0.25 for pigs, 0.13 for small ruminants, and 12.50 per 1,000 head of poultry. *Fertilizer* is the amount of major inorganic nutrients applied to agricultural land annually, measured as metric tons of N, P_2O_5, and K_2O equivalents. *Farm machinery* is the number of riding tractors in use. All of these series are available through 2007 except for farm machinery, which ends in 2006. I estimate tractors in use for 2007 by taking the average rate of growth in this variable over 2003-2006, except for China, the United States, and Brazil for which these are from government statistical sources.

While these inputs account for the major part of total agricultural input usage, there are a few types of inputs for which complete country-level data are lacking, namely, use of chemical pesticides, seed, prepared animal feed, veterinary pharmaceuticals, other farm machinery besides riding tractors, energy, and farm structures. However, data on many of these inputs are available for the nine country case studies I use for constructing the representative input cost shares. To account for these inputs, I assume that their growth rate is correlated with one of the five input variables just described and include their cost with the related input. For example, services from capital in farm structures as well as irrigation fees are included with the agricultural land cost share; the cost of chemical pesticide and seed is included with the fertilizer cost share; costs of animal feed and veterinary medicines are included in the livestock cost share, and other farm machinery and energy costs are included in the tractor cost share. So long as the growth rates for the observed inputs and their unobserved counterparts are similar, then the model captures the growth of these inputs in the aggregate input index.

2.3. Land Quality

The FAOSTAT agricultural database provides time-series estimates of agricultural land by country and divides these estimates into cropland (arable and permanent crops) and permanent pasture. It also provides an estimate of area equipped for irrigation. The productive capacity of land among these categories and across countries can be very different, however. For example, some countries count vast expanses of semi-arid lands as permanent pastures even though these areas produce very limited agricultural output. Using such data for international comparisons of agricultural productivity can lead to serious distortions, such as significantly biasing downward the econometric estimates of the production elasticity of agricultural land (Peterson 1987; Craig, Pardey, and Roseboom 1997). In two recent studies of international agricultural productivity, Craig, Pardey, and Roseboom (1997) and Wiebe et al. (2003) took considerable effort to include in their regression models variables that could account for differences in land quality (such as indexes of average rainfall and soil type, the proportion of irrigated or pastureland in total agricultural land, and fixed-effect models with regional or country dummies), and obtained estimates of production elasticities that were more in line with observed land cost shares.

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

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

The coefficient vectors α, β and γ provide the quality weights for aggregating the three land types into an aggregate land input index. Countries with a higher proportion of irrigated land are likely to have higher average land productivity, as will countries with more cropland relative to pastureland. The estimates of the parameters in equation (4) reflect these differences and provide a ready means of weighting the relative qualities of these land classes. Because of the limited amount of irrigated cropland in some regions, the coefficient on *IRRIG* was held constant across all developing country regions.

The results of the regression in equation (4) are shown in Table 4.1. All the coefficients are statistically significant and the variables explain about 75% of the cross-country variability in land productivity. The lower part of the table translates the estimated coefficients into average land productivities in dollars of output per hectare by land type. The results show that, on average, one hectare of irrigated land was more than twice as productive as rain-fed cropland, which in turn was 10-20 times as productive as permanent pasture, with some variation across regions. The results appear to give plausible weights for aggregating agricultural land across broad quality classes. In fact, this approach to account for land quality differences among countries is similar to one developed by Peterson (1987). Peterson regressed average cropland values in U.S. states against the share of irrigated and unirrigated cropland and long-run average rainfall. He then applied these regression coefficients to data from other countries to derive an international land quality index. The advantage of my model is that it is based on international rather than U.S. land yield data and provides results for a larger set of countries. Moreover, what are important for the growth accounting exercise are only the relative productivities, as these become the quality weights for aggregating land changes within a country.

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

Table 4.1. Estimation of land quality weights

Regression estimates

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

Note: All coefficients significant at the 1% level.

Regression statistics

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

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

Implied average productivities from the regression estimates

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

Table 4.2. Global agricultural land-use changes

A. Raw totals (millions of hectares)

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

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

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

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

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

2.4. Input Cost Shares

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

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

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

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

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

Table 4.3. Continued

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

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

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

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

2.5. Limitations

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

[2]For the purpose of estimating long-run productivity trends, I aggregate some national data to create consistent political units over time. For example, data from the nations that formerly constituted Yugoslavia were aggregated in order to make comparisons with productivity before Yugoslavia's dissolution; data were aggregated similarly for Czechoslovakia and Ethiopia. Because some small island nations have incomplete or zero values for some agricultural data, I constructed three composite "countries" by aggregating available data for island states in the Lesser Antilles, Micronesia, and Polynesia, respectively. This also enables a more detailed examination of regional patterns of agricultural productivity growth. The only countries or regions not included in the analysis are the Palestinian Territories, Western Sahara, Greenland, Liechtenstein, Andorra, and a number of very small urban or island states and dependencies.

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

3. RESULTS

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

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

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

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

Table 4.4. Continued

Asia				**Former Soviet Union**		
Developed	**NE Asia, developing**	**Southeast Asia**	**South Asia**	**Baltic**	**E. Europe**	**CAC**
Japan	China	Brunei	Afghanistan	Estonia	Belarus	Armenia
Korea, Rep.	Korea, DPR	Cambodia	Bhutan	Latvia	Kazakhstan	Azerbaijan
Taiwan	Mongolia	Indonesia	Nepal	Lithuania	Moldova	Georgia
Singapore		Laos	Sri Lanka		Russian Fed.	Kyrgyzstan
		Malaysia	Bangladesh		Ukraine	Tajikistan
		Myanmar	India			Turkmenistan
		Philippines	Pakistan			Uzbekistan
		Thailand				
		Timor Leste				
		Viet Nam				
Europe			**West Asia & North Africa**		**Oceania**	
Northwest	**Southern**	**Transition**	**North Africa**	**West Asia**	**Developed**	**Developing**
Austria	Cyprus	Albania	Algeria	Bahrain	Australia	Fiji
Belgium-Lux.	Greece	Bulgaria	Egypt	Iran	New Zealand	Micronesia [a]
Denmark	Italy	Czechoslovakia [b]	Libya	Iraq		New Caledonia
Finland	Malta	Hungary	Morocco	Israel		PNG
France	Portugal	Poland	Tunisia	Jordan		Polynesia [a]
Germany	Spain	Romania		Kuwait		Solomon Is.
Iceland		Yugoslavia [b]		Lebanon		Vanuatu
Ireland				Oman		
Netherlands				Qatar		
Norway				Saudi Arabia		
Sweden				Syria		
Switzerland				Turkey		
UK				UAR		
				Yemen		

[a] Composite countries composed of several small island nations.
[b] Statistics from the successor states of Ethiopia (Ethiopia and Eritrea), Czechoslovakia (Czech and Slovak Republics), and Yugoslavia (Slovenia, Croatia, Bosnia, Macedonia, Serbia and Montenegro) were merged to form continuous time series from 1961 to 2007.

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

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

Table 4.5. Continued

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

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

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

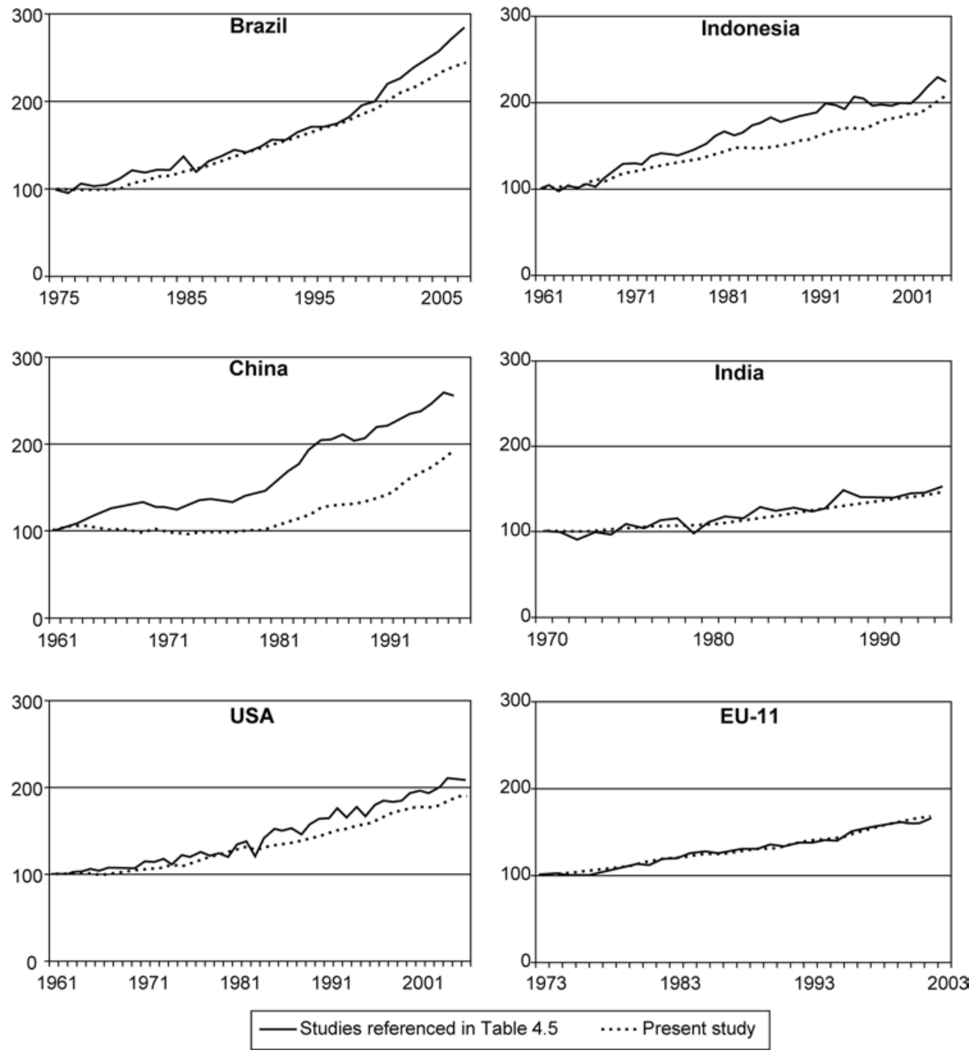

Figure 4.1. Comparison of agricultural TFP indexes (index equals 100 in initial year)

Table 4.6. Productivity indicators for world agriculture

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

Sources: FAOSTAT and author's calculations.

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

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

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

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

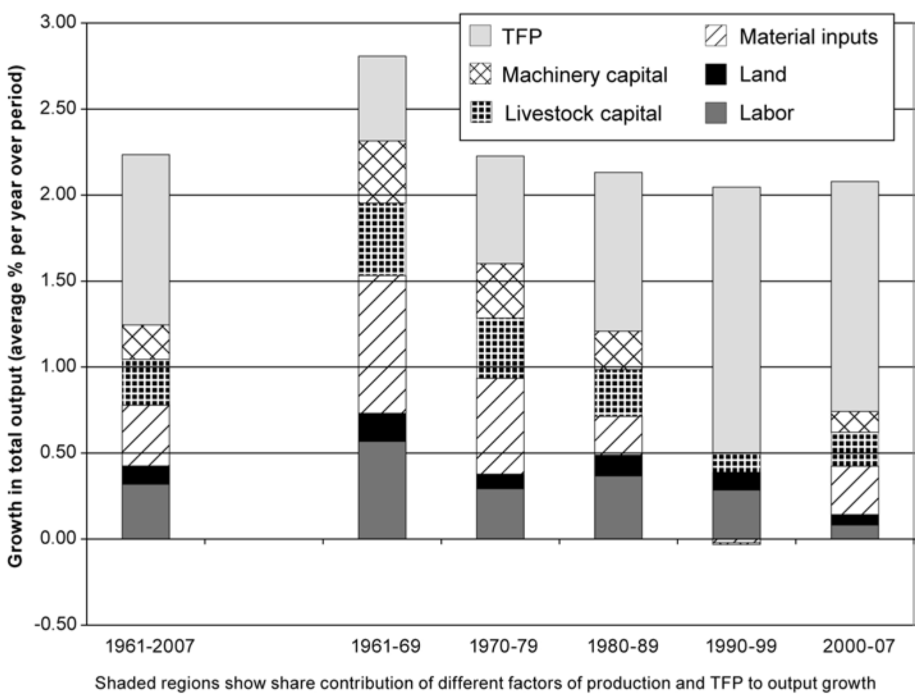

Figure 4.2. Sources of growth in global agriculture

Source: Author's estimates.

capital, machinery capital, and material inputs) by decade. In this figure, land is quality adjusted and the output trend has been filtered (but the filtering has a negligible effect on average global growth rates). Growth in material inputs, especially in fertilizers, was a leading source of agricultural growth in the 1960s and 1970s, when green revolution cereal crop varieties became widely available in developing countries. Fertilizer use also expanded considerably in the Soviet Union during these decades, where they were heavily subsidized. The long-run pattern shows that growth in agricultural production inputs gradually slowed, however, and the rate of increase in TFP accelerated to maintain real output growth at about 2% per annum. The exceptionally low rate of capital formation in global agriculture during the 1990s was due primarily to the rapid withdrawal of resources from agriculture in the countries of the former Soviet block. But many of the inputs used in these countries were apparently not efficiently applied, as their withdrawal significantly increased the average productivity of resources remaining in agriculture, evidenced by the high TFP growth rate in this decade. By 2000 agricultural resources in this region had stabilized and there was a recovery in the rate of global input growth compared with the 1990s.

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

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

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

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

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

Table 4.7. Continued

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

Source: Author's estimates.

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

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

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

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

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

4. CONCLUSION

Contrary to some other authors, I find no evidence of a general slowdown in sector-wide agricultural productivity, at least through 2007. If anything, the growth rate in agricultural TFP accelerated in recent decades, in no small part because of rapid productivity gains in several developing countries, led by Brazil and China, and more recently to a recovery of agricultural growth in the countries of the former Soviet bloc. However, the results do show clear evidence of a slowdown in the growth in agricultural investment: the global agricultural resource base is still expanding but at a much slower rate than in the past. These two trends—accelerating TFP growth and decelerating input growth—have largely offset each other to keep the real output of global agriculture growing at slightly more than 2% per year since the 1970s. This finding has important implications for the appropriate supply-side policy response to the recent rise in real agricultural prices.

One implication is that we should be optimistic about the prospects for global agriculture to respond to the recent commodity price rises by increasing supply in the short run. If TFP were slowing down, it would likely take several years for policy responses to influence this trend. The principal policy lever to increase TFP growth is to increase spending on agricultural research, but there are long time lags between research investments and productivity growth. But the main trend identified in this chapter is a slowdown in the rate of growth in agricultural capital formation. This is at least in part a consequence of a long period of unfavorable prices facing producers, who found better opportunities for their capital outside of agriculture. It was also in part a consequence of the institutional changes in the countries of the former Soviet block that precipitated a rapid exit of resources from agriculture in the 1990s. The incentives afforded by the current high commodity prices and a resumption of agricultural growth in the former Soviet countries should positively affect the rate of agricultural capital formation at the global level. So long as TFP growth continues at its recent historical pace, this should lead to an increased rate of real output growth in global agriculture in a relatively short period of time.

Despite this generally optimistic conclusion, it is also clear that agricultural productivity growth has been very uneven. The evidence in this chapter suggests TFP growth may in fact be slowing in developed countries while accelerating in developing countries. This is in marked contrast to the early findings of Hayami and Ruttan (1985) and Craig, Pardey, and Roseboom (1997), which found developing countries to be falling further behind developed countries in agricultural land and labor productivity. Nonetheless, it remains true that many developing countries have not been able to achieve or sustain productivity growth in agriculture and as a consequence suffer from low levels of rural welfare and food security. This has not contributed to a *slowdown* in global TFP growth of the sector because their growth rates were never high to begin with. But this certainly has led to agriculture performing below its potential and has kept these countries poor. The largest group of countries in this low-growth category is in Sub-Saharan Africa, but also included are many countries in West Asia, the Caribbean, and Oceania as well as some others.

There is also evidence that agricultural productivity growth has been uneven across commodities. However, our ability to assess productivity growth at the commodity level is limited mainly to examining land yield trends since labor and capital inputs tend to be shared across multiple commodities in the production process. Thus, the slowing growth in cereal grain yield that was identified in the *World Bank Development Report 2008* (World Bank 2007) does raise concerns that there is underinvestment (or low returns) to research directed at these commodities. But even here the picture is uneven, as decomposing cereal yield trends reveal that the slowdown affected primarily wheat and rice yields, with corn yield growth continuing to perform well after 1990. It is possible that the relatively strong performance in corn yield growth is due to the historically higher level of investment in research and development (R&D) for this crop because of the strong private-sector interest in breeding for hybrid corn (Fuglie et al. 1996). In any case, the implication for R&D policy is quite different than if a sector-wide productivity slowdown were occurring. Rather than comprehensive changes to agricultur al R&D or investment policies, the uneven performance within the agricultural sector suggests a more selective approach that requires a clear understanding of the causes of low productivity growth in particular commodities and countries.

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Part 2

Country-Specific Evidence

CHAPTER 5

Agricultural Productivity Growth in Australia and New Zealand

John Denis Mullen

1. INTRODUCTION

Productivity growth in Australian agriculture has been an important source of wealth in Australia. The real value of agricultural production in Australia has been over $40 billion (2008 Australian dollars) per year since the late 1990s (Figure 5.1). If productivity has grown at a rate of 2% per year, as some estimates indicate, then about two-thirds of the value of production in recent years can be attributed to productivity growth since 1953. Productivity growth has been strong in Australian agriculture relative to other sectors of the Australian economy and relative to the agricultural sectors of other rich countries (Mullen and Crean 2007).

Recent data, however, suggest that productivity growth in at least some important sectors of Australian agriculture may be slowing. Public investment in agricultural research in Australia, always the predominant source of funding in Australia, has been falling for several decades. Other causes of the decline in the rate of productivity growth are a series of bad seasons extending back to 2001, which may, in part, be attributed to climate change.

The objectives of this chapter are as follows:

- To review productivity growth in the Australian agriculture, fisheries, and forestry sector as a whole relative to the Australian economy as an indicator

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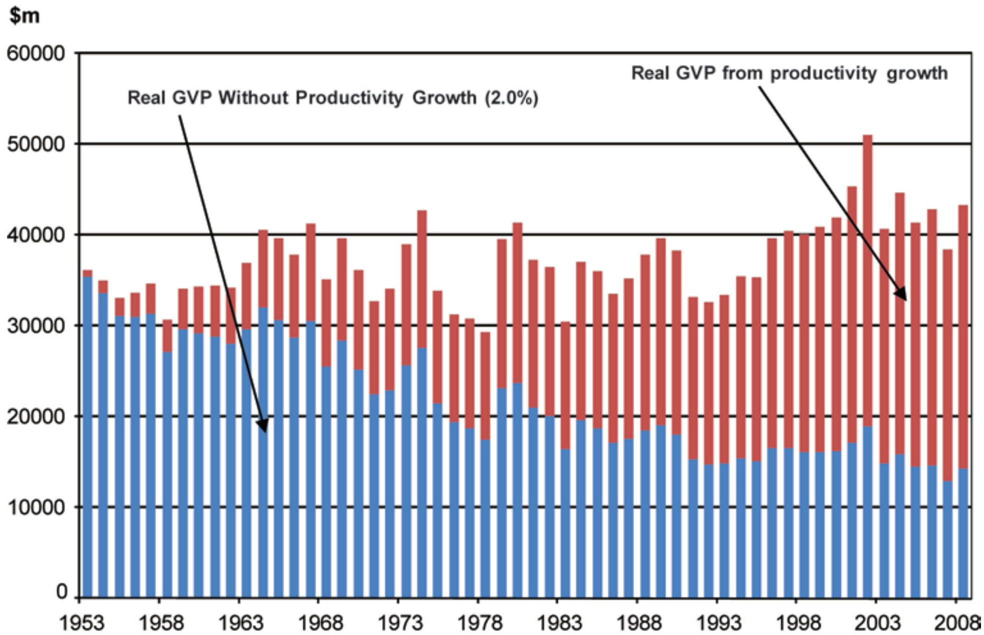

Figure 5.1. Value of productivity growth in Australia: 1953 to 2008
Source: Adapted from Mullen and Crean (2007) using data from 2003.

of the competitiveness of the sector domestically and internationally using value-added estimates of productivity growth from the Australian Bureau of Statistics (ABS). The performance of the agricultural sector within the New Zealand economy is also briefly reviewed.

- To review productivity growth within the cropping and livestock industries that comprise broadacre agriculture and within the dairy industry in Australia using gross output measures from farm survey data of the Australian Bureau of Agricultural and Resource Economics (ABARE).
- To assess whether productivity growth in agriculture has slowed and review potential sources of this slowdown.

2. AGRICULTURE IN THE AUSTRALIAN ECONOMY

The 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.[1] Estimates of multifactor productivity

[1]In the value-added approach, the value of intermediate inputs is deducted from the gross value of output, and inputs are a correspondingly reduced set—often only labor and capital used in the sector.

(MFP) growth for the agriculture, fisheries, and forestry sector and other sectors are provided at five-year intervals from 1986 (Table 5.1) (ABS 2007).[2,3]

The agricultural sector has been ranked with the communication services sector and the finance and insurance sector as high-growth sectors in the Australian economy. Productivity in the Australian market economy grew at a rate of 1.2% per year

Table 5.1. Compound annual percentage change in value added–based MFP, market sector industries

	1985–86 to 1990–91	1990–91 to 1995–96	1995–96 to 2000–01	2000–01 to 2005–06	1985–86 to 2005–06
			percent		
High					
Communication services	4.7	4.7	2.2	2.7	3.6
Agriculture, forestry, & fishing	2.3	1.8	5.3	2.5	3.0
Finance & insurance	3.1	2.0	2.0	0.2	1.8
Medium					
Transport & storage	0.7	2.9	1.7	1.6	1.7
Wholesale trade	-1.8	3.9	2.9	1.3	1.5
Electricity, gas, & water	6.0	2.6	0.5	-3.2	1.4
Low					
Retail trade	-1.0	1.1	2.2	0.7	0.7
Manufacturing	0.9	0.5	1.1	0.4	0.7
Construction	-1.8	0.2	—	4.5	0.7
Mining	3.5	2.3	1.1	-5.9	0.2
Accommodation, cafes, & restaurants	-3.8	—	1.4	2.5	—
Cultural & recreational services	-0.9	-2.2	0.8	-0.2	-0.6
Market sector	**0.8**	**1.6**	**1.6**	**0.8**	**1.2**
Ratio of agriculture to market	**2.9**	**1.3**	**3.3**	**3.1**	**2.5**

Source: Adapted from ABS 2007, available at http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/ 5260.0.55.0022007-08?OpenDocument.

[2]The ABS also presents MFP estimates for the market economy for growth cycles in which growth peaks are estimated as local maximum divergences in the MFP from a trend MFP estimated used a smoothing process such as an 11-term Henderson moving average. However, productivity cycles at an industry level are unlikely to coincide.

[3]Most often the data in ABS 2007 refer to financial years, but the convention of referring to the 1985-86 year as 1986, for example, has been adopted.

over the entire period from 1986 to 2006. It surged strongly in the 1990s, growing by 1.6% per year, but slowed to 0.8% per year for the five years leading up to 2006.

Over the 1986-2006 period, productivity in the agriculture, fisheries, and forestry sector grew at an annual rate of 3.6%, 2.5 times that of the market economy. In three of the four subperiods, MFP in the agriculture sector grew at about 3 times the rate of the market economy.

Studies by Bernard and Jones (1996) and Martin and Mitra (2000) suggest that the agricultural sectors in few OECD (Organization for Economic Cooperation and Development) countries have performed as well relative to their economies as has the Australian agricultural sector. Hence, productivity growth in the Australian agricultural sector has likely been strong enough to enhance the sector's competitiveness relative to other sectors of the Australian economy and relative to the agricultural sectors in many other countries.[4]

Despite this apparently strong productivity performance of the agriculture, fisheries, and forestry sector relative to the market economy, the share of the sector in total Australian gross domestic product (GDP) has continued to decline (from 9.8% in 1964 to 2.5% in 2008) although the rate of decline has eased markedly since the late 1980s.

Over the longer period, 1978 to 2007, the average annual rate of growth in productivity in the agricultural sector at 2.4% was twice that of the market economy, at 1.2%.[5,6] Labor productivity in agriculture (value-added output per unit of labor [hours worked]) grew at a rate of 2.1% per year, faster than capital productivity (value-added output relative to a flow of services from a measure of the productive capacity of capital), and the capital-to-labor ratio (the ratio of these two partial productivity indexes) increased from less than 70 in 1978 to 100 in 2007, consistent with capital being substituted for labor.

To provide some perspective, real GDP (in 2008 Australian dollars) in the Australian economy in 2008 was $1,037 billion with the contribution of agricul-

[4]The qualification here is that the market economy estimates do not include property and business services, government administration and defense, education, health and community services, and personal and other services, sectors for which output is valued at cost. The relative performance of the agriculture sector may be overstated if productivity in these sectors not presently included has grown at a faster rate than the market economy.

[5]MFP growth rates were estimated as the coefficient on a time trend in a regression of the log of MFP against a constant and the time trend.

[6]ABS data are now available to 2008 (Figure 5.6) but ABARE data are only available to 2007. The extra year does not alter these estimated growth rates.

ture being \$21.7 billion (2.1%) and that of fisheries and forestry being \$2.3 billion (0.2%) (ABARE 2008).

There is an important distinction between value-added measures of MFP (reported in Table 5.1) and gross output measures of MFP (also reported by ABS for the period 1995-2004 and used exclusively by ABARE) (ABS 2007). The gross output measure is based on the total value of production of firms engaged in agriculture, fisheries, and forestry. The input measure used in estimating MFP is the total value of labor, capital, and all intermediate inputs. The value-added measures exclude the value of intermediate inputs both from the measure of outputs and the measure of inputs. The gross output measure has the attraction of attributing efficiency gains across all inputs and hence is more closely interpreted as Hicks-neutral technical change in an industry. The value-added measure is more partial in nature, attributing efficiency gains to labor and capital. However, the attractions of the value-added measure include ease of aggregation from industries to a market-economy measure of MFP and the timeliness by which the measure can be derived from national accounts data.

The growth in the gross output MFP measure can be derived as the growth in the value-added MFP measure times the ratio of nominal value-added to nominal gross output (ABS 2007). This relationship means that the growth in the gross output measure is flatter than the growth in the value-added measure. This will be an important consideration when comparing the ABS value-added and ABARE gross output measures of MFP in the following sections.

3. PRODUCTIVITY GROWTH IN NEW ZEALAND AGRICULTURE

There have been a number of studies of productivity growth for the New Zealand economy and its agriculture sector (including Philpott and Stewart 1958; Diewert and Lawrence 1999; Black, Guy, and McLellan 2003; Hall and Scobie 2006; Cao and Forbes 2007; and Mullen, Scobie, and Crean 2008). These studies are difficult to compare because of the different datasets and methodologies used to compute MFP. Statistics New Zealand did not start reporting productivity measures until 2006 and then only for the market economy (defined similarly to ABS). Attention here is confined to the Hall and Scobie research, because of its longer historical perspective, and the most recent analysis by Cao and Forbes from the Ministry of Agriculture and Fisheries (MAF), which is based on Statistics New Zealand data. All of the studies used value-added measures of MFP, and MFP growth was estimated as a compound annual growth rate.

Hall and Scobie (2006) constructed an MFP series for the years 1927-2001 using a value-added approach. They estimated that, over the entire period 1927–2001, their measure of MFP grew at a rate of 1.8% per year. The average annual growth rates by subperiod were 1.0% (1927-56), 2.2% (1957-83), and 2.6% (1984-2001).[7] The trend in productivity in New Zealand agriculture is graphed in Figure 5.2 for the period 1953 to 2001. It is noteworthy that this period of accelerating MFP from 1984 coincides with a period of major economic reform within the New Zealand economy.

The MAF publishes a value-added series (based on Statistics New Zealand data) for the years 1978 to 2007. Hall and Scobie have not updated their series, and the two series are unlikely to be perfectly consistent.

Using this MAF series, Cao and Forbes estimated that for the period 1988-2006, MFP in agriculture (not including forestry and fisheries) grew at a rate of 2.7% per year, which was 1.8 times faster than MFP growth of 1.5% per year for the market economy as estimated by Statistics New Zealand (Figure 5.3).[8] As for Australia, labor productivity in New Zealand agriculture grew more quickly than capital productivity, and input use declined. There is little evidence that growth in productivity in New Zealand agriculture has slowed.

Given that the Cao and Forbes measure of MFP is a value-added measure (expected to be steeper than a gross output measure) and that MFP growth in New Zealand agriculture has not been as fast relative to the New Zealand market economy as has been the case in Australia, it seems most probable that productivity growth has been faster in Australian agriculture than in New Zealand agriculture. The most recent multilateral study by Rao, Coelli, and Alauddin (2004) found that MFP growth rates in Australia and New Zealand over the period 1970-2001 were 2.0% and 0.8% per year, respectively.

In each of the figures for the Hall and Scobie and MAF series on MFP in agriculture, a terms-of-trade index has been graphed (Figures 5.2 and 5.3). For Hall and Scobie this index was estimated as the ratio of an index of output prices to an index of input prices from their productivity database. The Hall and Scobie (2006) series declined from around 176 in 1953 to 100 in 2004. This is a much slower rate of decline than that faced by Australian farmers as will be

[7]Mullen, Scobie, and Crean (2008) reported lower growth rates because they re-estimated them from a regression of the log of MFP against a constant and time trend.

[8]The MAF series now extends back to 1978, but when Cao and Forbes did their analysis only data from 1988 were available.

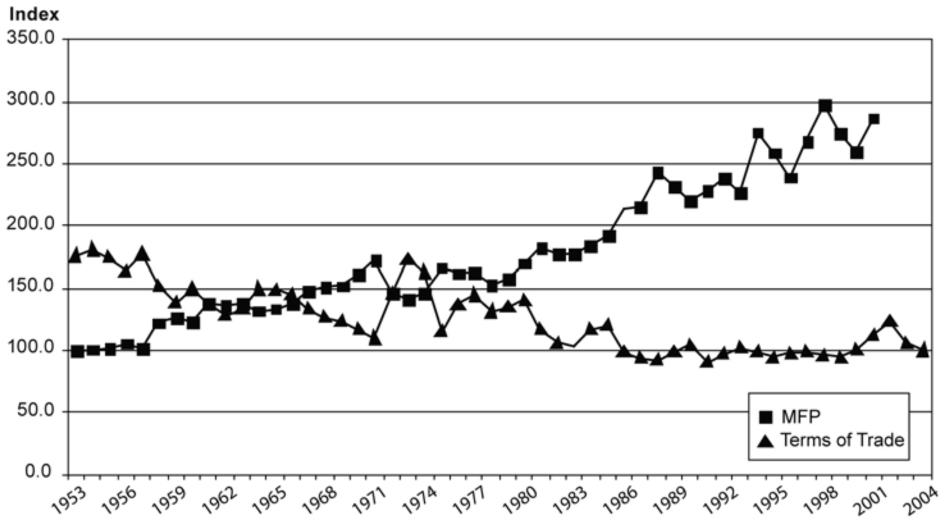

Figure 5.2. Productivity growth and terms of trade in New Zealand agriculture from Hall and Scobie: 1953 to 2001

Source: Hall and Scobie 2006: terms of trade is estimated as the ratio of an index of output prices to an index of input prices, and MFP is a value-added measure.

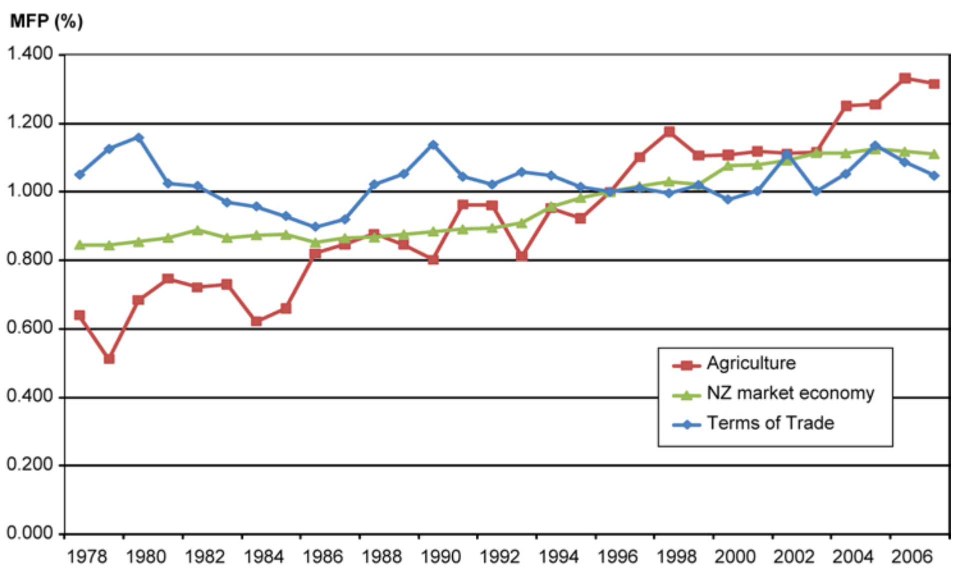

Figure 5.3. MFP for New Zealand agriculture and the New Zealand market economy from MAF: 1978 to 2007

Source: MAF, available at http://www.maf.govt.nz/mafnet/rural-nz/statistics-and-forecasts/sonzaf/2008/tables/A-4.xls. Terms of trade is estimated as the ratio of an index of prices received for exports to an index of prices paid for imports, and MFP is a value-added measure.

seen in what follows. Cao and Forbes estimated the terms of trade as the ratio of an index of prices received for exports to an index of prices paid for imports. The two series are different, but both suggest that there has been no trend in the terms of trade for the New Zealand farm sector since the late 1980s, similar to the experience of Australian farmers. As a consequence, the gains to New Zealand (and Australian) farmers from productivity growth were not offset by unfavorable price changes during this recent period.

Mullen, Scobie, and Crean (2008) suggested that while public research intensity in Australia has been about twice that in New Zealand, returns to agricultural research in the two countries seemed similar, and hence relative levels of research investment seemed appropriate. The speculation that Australia has a larger agricultural sector and larger share of broadacre cropping (where MFP growth was most rapid, at least until 2000) may partly explain Australia's better performance.

4. PRODUCTIVITY GROWTH IN AUSTRALIAN BROADACRE AGRICULTURE

ABARE has conducted farm surveys over many years for broadacre agriculture, the extensive grazing and cropping industries, and for dairying. Data from these surveys are used to follow trends in productivity using gross output measures. Most farms in Australia jointly produce several crop and livestock commodities. ABARE monitors the productivity of segments within broadacre agriculture—such as specialist sheep (meat and wool) producers or specialist crop producers—but does so using stratified samples from their overall farm survey.

In 2008 the total value of crop production (Australian dollars) was $21.4 billion, of which grains and oilseeds comprised $9 billion. The total value of livestock production was $19.8 billion, of which dairying contributed $4.6 billion, wool, $2.6 billion, and livestock slaughtering (including extensive and intensive stock), $12.1 billion (ABARE 2008).

I assembled an MFP series for the years 1953 to 1994 using ABARE farm survey data, which I extended subsequently in a piecemeal fashion, again using ABARE data, as reported in several papers, most recently a 2007 article in the *Australian Journal of Agricultural and Resource Economics*. Recently, the dataset was updated by integrating it with ABARE's complete MFP data for the period 1978 onward to yield a consistent productivity dataset for 1953 to 2007.

Alongside yearly additions to ABARE's dataset (as each survey is completed), ongoing revisions to previous years are made in "cleaning" the data. The accumulated effect of these small changes over a number of years means that re-estimating earlier estimates can yield substantially different results. For example, using the new dataset, average MFP growth between 1978 and 2004 is estimated at 1.7% a year, compared to 2.7% using the dataset from Mullen 2007. As new estimates reflect the latest data revisions, it appears that my earlier estimates and those of ABARE most likely overstated broadacre productivity growth.

There have also been changes in ABARE's survey and survey methodology over time, which can influence MFP estimates. For example, the sampling frame adjusts from year to year based on a population drawn from the ABS Australian Business Register, and hence individual farms are not consistently surveyed. Also, the target population is revised over time to reflect changes in the value of farm production. Since 2004-05, the ABARE survey has included farm establishments with an estimated value of agricultural operations of $40,000 or more. In earlier years, excluding the smallest farms required a smaller cut-off. Finally, in 2002, the survey definitions of farm capital inputs were changed.[9] These changes mean that in evaluating differences in the rate of agricultural productivity growth across time periods it is important to use a consistent dataset, and comparing reported estimates across a range of literature can be misleading.

The index of MFP for Australian broadacre agriculture increased almost threefold, from 100 in year 1953 to 288 in 2000. It then declined to 193 in 2003, reflecting the drought in that year, before reaching 277 in 2006 and then falling to 215 in the drought year of 2007 (Figure 5.4). The index is highly variable, falling in 20 of the 55 years, reflecting seasonal conditions (Figure 5.5). Such variability makes it difficult to discern trends in the underlying, more stable rate of technological change. The average annual rate of MFP growth over the entire period was 2.0% per year, 0.5% per year lower than the long-term rate I previously reported (in Mullen 2007, for example).

Changes in productivity can be compared with changes in the terms of trade faced by farmers[10] as a partial indicator of whether Australian agriculture is becoming more or less competitive. The conventional wisdom is that the terms of trade facing Australian agriculture have been declining inexorably. However,

[9]Further details of ABARE survey methods can be found in ABARE 2009.

[10]Reported in ABARE 2008 and estimated as the ratio of an index of prices received by farmers to an index of prices paid by farmers.

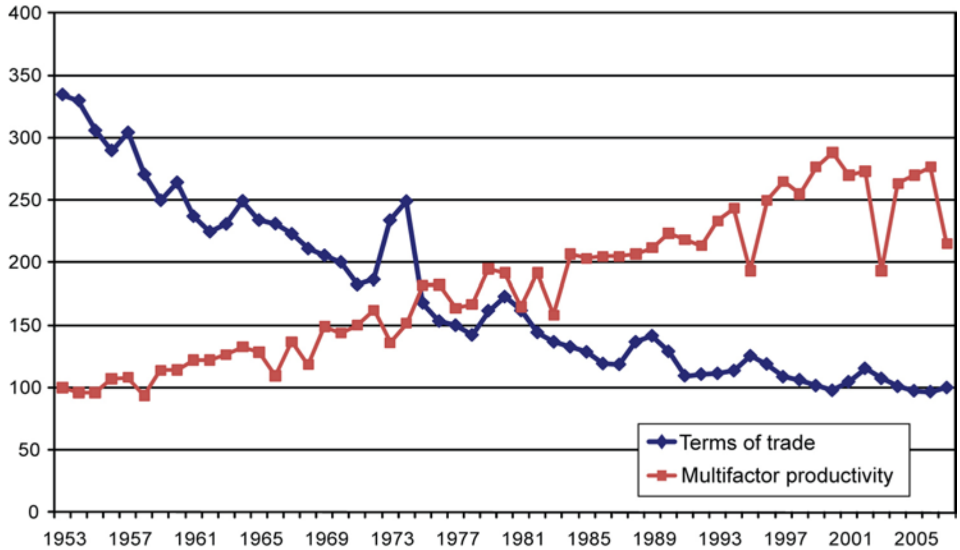

Figure 5.4. Broadacre MFP and terms of trade in Australian agriculture: 1953 to 2007

Source: Terms of trade is estimated as the ratio of an index of prices received by farmers to an index of prices paid by farmers (ABARE, Australian Commodity Statistics, 2008) and MFP is a gross output measure.

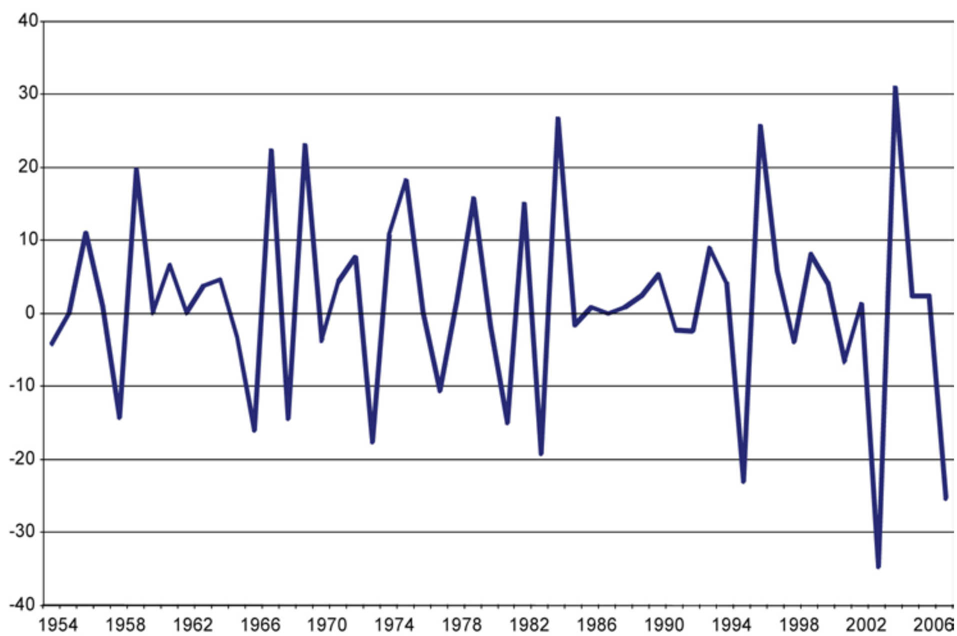

Figure 5.5. Annual growth rates for MFP in Australian broadacre agriculture

Source: Adapted from Mullen and Crean 2007.

while the terms of trade declined for about 40 years from 1953 (Figure 5.4), since the early 1990s, the rate of decline has been much slower, at least for the sector as a whole. While the MFP index grew from 100 in 1953 to 215 in 2007, the terms of trade declined from about 335 to 100, at a rate of 2.3% per year over the period 1953 to 2007, faster than the rate of productivity growth in broadacre agriculture. However, the rate of decline was 2.6% per annum from 1953 to 1990, and from 1991 to 2007, it was less than 1.0% per annum.

The ABARE estimates of productivity growth in broadacre agriculture can also be compared with the ABS estimates for agriculture, fisheries, and forestry (Figure 5.6). For the period 1978 to 2007, the ABARE and ABS estimates of average annual productivity growth rates were 1.5% and 2.4%, respectively. The ABARE and ABS series tracked each other closely except from 2001 when the ABARE series dipped while the ABS series continued to rise.

The most important reason for the much faster growth rate of the ABS measure is that it is a value-added measure. The ABS also report a gross output measure for the years 1995 to 2004, which is noticeably flatter than the ABS value-added series over the same period and similar to the ABARE series (Figure 5.6). In fact, the annual growth rates over this 10-year period were 2.1%, 2.2%, and 4.4% for the ABARE, ABS gross output, and ABS value-added measures, respectively.

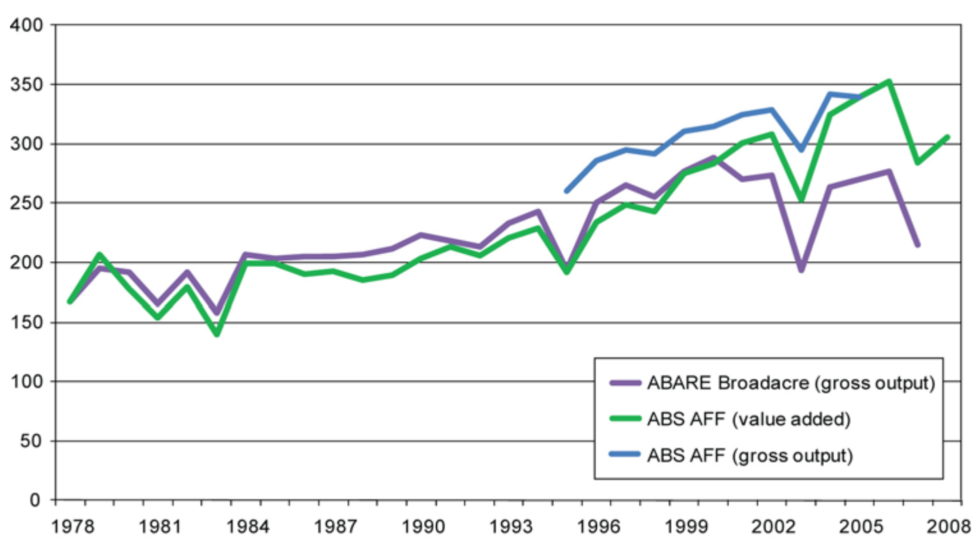

Figure 5.6. MFP trends as estimated by ABARE for broadacre agriculture and by the ABS for agriculture, fisheries, and forestry using value-added and gross-output measures

In addition, the industry coverage of the ABS and ABARE series is different. The ABS measure includes all agriculture, forestry, and fisheries, whereas the ABARE measure covers broadacre including extensive livestock and cropping industries but not including important industries like dairying, intensive livestock, horticulture, and viticulture. The share of broadacre agriculture in total value of output from agriculture (not including forestry and fisheries) has fallen to about 60%. Because of the run of poor seasons over the past decade, which has had more severe impacts on broadacre agriculture than other components of the sector, there has been a divergence in the growth of MFP for broadacre agriculture and that for the agriculture, fisheries, and forestry sector.

Productivity growth in broadacre agriculture since 1978 reflects output growing by 0.8% per year combined with input use declining by 0.6% per year (Nossal et al. 2009). Labor use declined (1.7%) faster than the use of capital (1.2%) and land (0.7%) while the use of purchased inputs increased (2.4%), resulting in higher rates of growth in partial factor productivity (PFP) of labor (2.5%) and capital (2.1%).

As noted earlier, the ABARE broadacre dataset was stratified based on the Australian and New Zealand Standard Industrial Classification (ANZSIC) system to provide estimates of productivity growth by the enterprise or industry.[11]

Here I have adopted the same stratification: cropping, mixed crop–livestock, beef, and sheep. Alternative definitions have been used for specific industry analyses (as in Nossal, Sheng, and Zhao 2008), but the findings were not dissimilar.

Since 1978, cropping specialists have achieved much higher rates of MFP growth (2.2% per year) than have beef specialists (1.5% per year) and sheep specialists (0.3% per year) (Table 5.2). Generally output grew while input use stayed static or declined. In particular, cropping specialists greatly increased their use of purchased inputs (4% per year) and reduced their use of labor (-0.2% per year) and capital (-0.4% per year), resulting in strong growth in partial productivity of labor and capital (Nossal et al. 2009). A switch toward reduced-tillage cropping—which is also associated with more diverse cropping rotations and more opportunistic cropping to exploit available soil moisture (as opposed to fixed rotations and fallows)—partly explains the changes in input use and the strong rate of productivity growth.

[11]ANZSIC is consistent with international standards and permits comparisons between industries, both within Australia and internationally. Farms assigned to a particular ANZSIC class have a high proportion of their total output characterised by that class (ABS 2006, cat. no. 1292.0).

Table 5.2. Average annual growth in broadacre MFP, by industry and by state, 1978 to 2007

	Percentage Growth		
	MFP	Output	Input
Total broadacre	1.5	0.8	-0.6
Cropping	2.1	3.1	1.0
Mixed crop/livestock	1.5	0.1	-1.5
Beef	1.5	1.7	0.1
Sheep	0.3	-1.4	-1.8
New South Wales	1.2	0.3	-0.9
Victoria	1.4	0.6	-0.8
Queensland	0.8	0.6	-0.2
South Australia	2.0	1.5	-0.5
Western Australia	2.4	1.8	-0.6
Tasmania	0.8	-2.1	-2.9
Northern Territory (Beef)	1.7	1.6	-0.1

Sources: Nossal et al. 2009 for the industry data. The state data come from the same database but were not published in Nossal et al. 2009.

Wheat yield, about 2 tons per hectare in good years, grew by 0.9% per year on average since 1972, or by 1.5% per year if the drought years of 2007 and 2008 are omitted (Figure 5.7). Wool cut per head, which in good years approaches 6 kilograms per head, grew by 0.2% per year.[12] Perhaps growth in these yields has slowed since the mid-1990s, but a run of poor seasons confounds any firm conclusions.

It is not clear why MFP has grown more quickly in cropping than in livestock, particularly in sheep production (Mullen 2007). The production cycle is much longer in livestock than in cropping, which may mean it is more difficult to demonstrate to farmers the benefits from new technologies. Perhaps genetic gains have been more rapid in crops than in livestock over this period. Perhaps specialist crop farmers have a greater range of input substitution and output transformation opportunities than specialist wool growers, for example. However my analysis with Crean (Mullen and Crean 2007) pointed out that the productivity gains of mixed farmers (who presumably have the greatest opportunities for economies of scope), while greater than those of specialist livestock farms, were less than those of specialist crop farmers. The Productivity Commission (2005) pointed to a rapid advance in cropping technologies as an explanation for this

[12]How wool cut per head translates into wool cut per hectare depends on stocking rate. Stocking rates typically decline during drought years but often not at a rate to maintain wool cut per head.

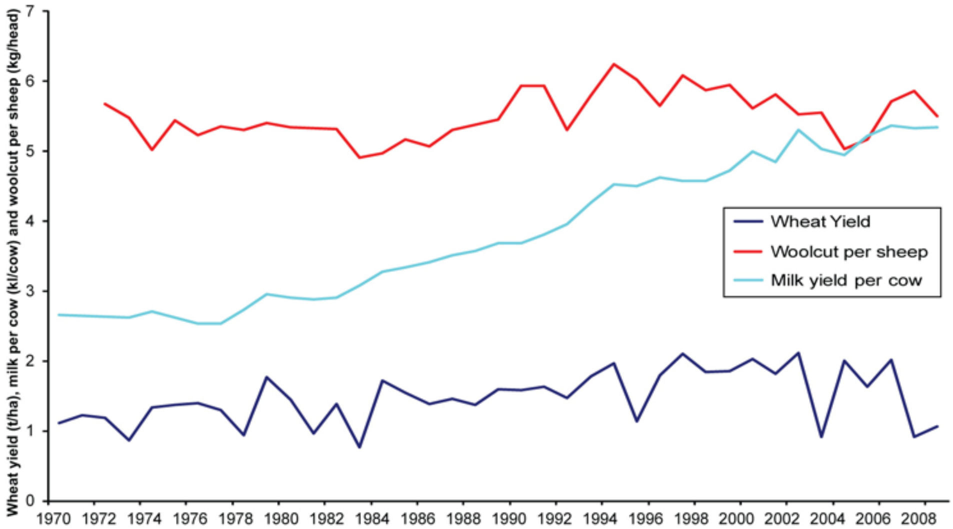

Figure 5.7. Yields of milk, wheat, and wool in Australia: 1970-2008
Source: Derived from data in ABARE 2008.

divergence in MFP growth. These technologies included higher-yielding, disease-resistant varieties; improved fertilizers and pesticides; and reduced tillage.

Productivity growth has also varied by state, with productivity growth much faster in Western Australia and South Australia than in New South Wales and Victoria. Hailu and Islam (2004), using a multilateral approach to compare broadacre MFP (based on ABARE data) across states from 1977 to 1999, found that faster growth in Western Australia and South Australia meant that MFP indexes were converging across states.

In several papers, Knopke and colleagues (1995, 2000) enquired into sources of Australian agricultural productivity growth. The most robust of their findings was that scale matters. Large farms have higher rates of productivity growth than small farms. Dividing the farms into three groups by size (measured in terms of livestock carrying capacity), Knopke et al. (1995) found that productivity grew by 3.1% per year for the group of largest farms, 1.9% per year for the group of medium-sized farms, and 0.9% per year for the group of smallest farms. In the 2000 study, Knopke et al. found that productivity grew by 3.5%, 2.7%, and 2.4 % per year respectively for the three groups of farms.[13]

[13]Note that the study by Knopke et al. (1995) analyzed the performance of broadacre farms generally, not just grain farms, as in later studies. The 2000 study did not include specialist livestock producers.

The most thorough attempt to quantitatively examine the sources of agricultural productivity in Australia was the study of the Australian grains industry by Alexander and Kokic (2005). Theirs was a cross-sectional study using individual farm data for Victorian grain farms from the ABARE broadacre survey for the years 1999 and 2002, as well as for 2001. Using an adjustment to the Fisher total factor productivity (TFP) formula to ensure transitivity,[14] they were able to compare the absolute *level* of productivity between farms. Their measure of TFP represents the extra output some farms gain holding constant the quantity of inputs.

Given the earlier findings that the key factor associated with higher levels of productivity was farm scale, with larger farms being more productive, Alexander and Kokic (2005) undertook regression analysis (M-quartile regression) to estimate unit production costs and their relationship with size. Their findings confirmed that costs per hectare were negatively related to farm size and productivity, meaning that smaller farms had higher costs per hectare and lower productivity.

Soil moisture generally had a statistically significant, positive effect on productivity in all regions and years. While farmers may be able to manage available soil moisture to some degree, rainfall is outside their control.

Other factors that generally had a positive and significant influence on productivity for grain farms in all regions included the use of reduced-tillage technologies, the extent of specialization in cropping, farmer education, and farmer participation in training. Off-farm income had a negative effect on productivity, but perhaps farm size is confounding this relationship, as small farms rely much more heavily on off-farm income.

While some other factors were significant in one or more regions in one or more years, their impact on productivity (either positive or negative) was not consistent. For example, soil acidity was negatively related to productivity in the northern and western regions in some years and positively related in the southern region in 2001-02.

In these studies, potential economies of scale were identified as a source of productivity growth. The Productivity Commission (2005) noted that average farm size in Australian agriculture (not just broadacre farming) has been increasing. In 1983 there were 178,000 farms and the average size was 2,720

[14]See Coelli et al. 2005, for example.

hectares. The ABS (2009) reported 141,000 farms in 2008 and an average size of 2,959 hectares.[15] The rate of increase in farm size was initially about 1% per year, but it has slowed in recent years. Hence, some share of estimated growth in Australian agricultural MFP may be attributable to increasing farm size. The policy implications of productivity growth relating to farm adjustment should be considered. That noted, changes in farm size occur quite slowly and, hence, may not have been a major contributor to recent productivity growth in Australian agriculture.

A major source of productivity growth has been from technical change arising from investment in research and development (R&D). The public sector, financed to a significant degree in recent decades by levies on production, has been the major provider of R&D services in Australia. In a series of analyses (most recently Mullen 2007) I found that the returns to this investment in broadacre agriculture have remained high (an internal rate of return of 15%-40% per year). However the downward revision of the ABARE productivity series for broadacre agriculture, previously noted, is likely to mean that my estimates are likely to be biased upward.

5. PRODUCTIVITY GROWTH IN AUSTRALIAN DAIRYING

Aside from the broadacre agricultural sector, ABARE data also enable productivity analysis of the dairy industry. The most recent study based on the revised ABARE dataset was reported in Nossal et al. (2009). MFP in dairying grew by 1.2% per year over the period 1989–2007, with output growing at a rate of 5.9% per year and inputs growing at a rate of 3.9% per year, a different experience from that of broadacre agriculture.[16] The dairy industry has responded to significant deregulation of marketing (particularly since July 2000), with small farms leaving the industry and the remaining farms growing in size and intensity.[17] Milk yields per cow grew at an average rate of 2.4% per year since 1972 and are approaching 5.5 kiloliters per cow per year. Total production of milk fell from 11.3 billion liters in 2002 to 9.1 billion liters in 2008.

[15]The ABS and Productivity Commission estimates may not be consistent but there is no doubting the trend.

[16]Note the shorter observation period—from 1989 for dairying as compared to 1978 for broadacre.

[17]Dairy farms now rely more heavily on purchased feed and irrigated pastures and are more likely to specialize in dairying.

Productivity grew the fastest in New South Wales, arguably where the gains from deregulation have been greatest (Zhao et al. 2008). In their data envelopment analysis of a cross-section of dairy farms, Fraser and Graham (2005) noted that dairy farms in New South Wales and Queensland in 2000 were farther from the efficiency frontier than those in Victoria, implying greater scope for productivity growth in those states as dairy farmers adjusted to deregulation.

6. HAS PRODUCTIVITY GROWTH IN AGRICULTURE SLOWED?

In Australia, a decade of poor seasonal conditions has made it difficult to discern whether and why agricultural productivity growth has slowed. According to the ABS valued-added measure, productivity growth in the agriculture, fisheries, and forestry sector has remained strong despite a weakening in the rest of the economy (Table 5.1), growing at a rate of 2.5% per year in the 10 years leading up to 2007.

However, ABARE estimates for broadacre agriculture suggest that productivity growth slowed in the 10 years leading up to 2007.[18] In this period, MFP peaked at 288 in 2000 and the next peak was 276 in 2006 (Figure 5.6). The annual growth rate from 1998 to 2007 was -1.4% (Table 5.3).

Recall that, were a gross output measure for the agriculture, fisheries, and forestry sector available for this period, its growth rate would be much flatter and more similar to the ABARE measure. Nevertheless, it seems highly likely that because of the different industry composition of the two measures and the greater susceptibility of broadacre industries to the impact of drought, MFP

Table 5.3. Trends in MFP for broadacre industries, 1978 to 2007

	All Broadacre	Cropping	Mixed Crop-Livestock	Beef	Sheep
			percent		
1979-80 to 1988-89	2.2	4.8	2.9	-0.9	0.4
1984-85 to 1993-94	1.8	4.7	3.2	3.1	-1.7
1988-89 to 1997-98	2.0	1.9	1.4	1.6	-1.2
1993-94 to 2002-03	0.7	-1.2	0.0	1.0	3.4
1997-98 to 2006-07	-1.4	-2.1	-1.9	2.8	0.5
1977-78 to 2006-07	1.5	2.1	1.5	1.5	0.3

Source: Nossal et al. 2009.

[18]Trends within enterprises that make up broadacre agriculture are reviewed in the next section.

growth in the agriculture, fisheries, and forestry sector has been faster than that in broadacre industries over the past decade.

Trends in productivity have not been even across industries within broadacre agriculture (Table 5.3). For cropping specialists, MFP grew by 4.8% per year from 1980 to 1994 but declined by 2.1% per year from 1998 to 2007. There seems much less evidence of a slowing in MFP growth for beef and sheep specialists. Nossal et al. (2009) speculated that productivity growth of sheep specialists, usually ranking the lowest among the industry groups, might finally be catching up.

Why might broadacre productivity be slowing? Some argue that it is not surprising that productivity growth in agriculture is drifting down because "all the big gains have been made." However, Australian research agronomists seem confident that there are still practical research opportunities to develop new technologies that would allow farmers to grow crops more efficiently. For example, Angus (2001) argued that trends in Australian wheat yields showed little signs of slowing down (Figure 5.8). Anderson and Angus (*World Wheat Book,* in press) said:

> "Despite the new technology, the mean yield is only 2.0 tons per ha, about half of the water-limited potential…. Further research will be needed to increase yield closer to the water-limited potential. The gains are most likely to come from tactics that enable crops to take advantage of the more favorable seasons in the variable climate, and concentration of inputs on the parts of farms with the highest yield potential."

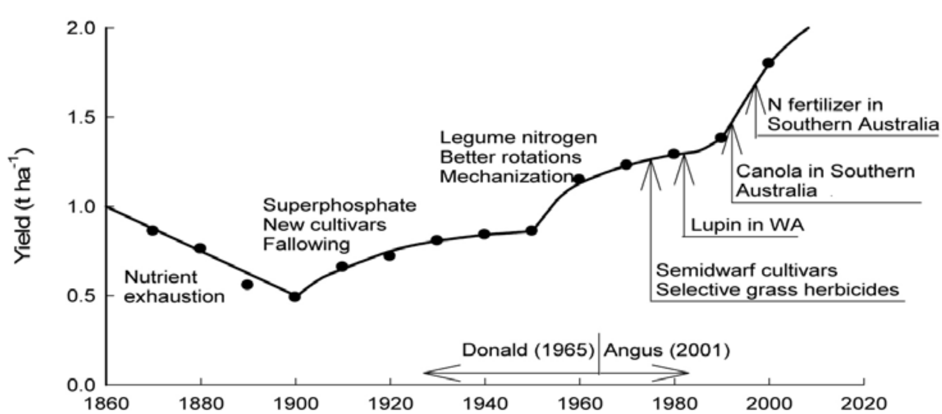

Figure 5.8. Trends in average wheat yield in Australia: 1860 to 2000
Source: Donald 1965, modified by Angus in 2001.

Two other factors likely to explain a significant portion of productivity growth in broadacre agriculture (at least at the aggregate level) are climate or seasonal conditions and public investment in agricultural research.

The annual rainfall anomaly for the Murray Darling Basin (Figure 5.9) published by the Bureau of Meteorology for the period 1900-2008 shows the annual deviation in rainfall from average annual rainfall between 1961 and 1990. There have now been eight consecutive years of below-average rainfall. No judgment is made here about the extent to which long-term climate change has contributed to this run of poor seasons. If farmers are using inputs in expectation of a normal season but a dry season eventuates, then MFP falls. In addition, perhaps farmers' expectations about seasons are now more conservative such that they are operating on a less efficient part of the production function.

Total public expenditure on agricultural R&D (not including fisheries and forestry) in Australia has grown from $140 million in 1953 to almost $830 million in 2007 (in 2008 Australian dollars) (Mullen 2010). Figure 5.10 shows that expenditure growth was strong to the mid-1970s. The trend in expenditure has essentially been static since that time, although there was a spike in investment (nearly $950 million) in 2001. Likewise, agricultural research intensity, which measures the investment in agricultural R&D as a percentage of GDP, grew strongly in the

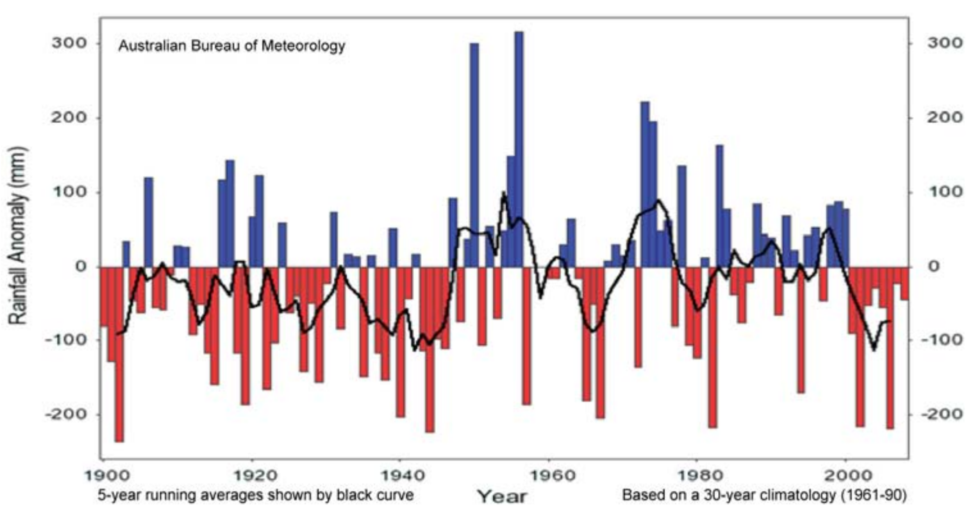

Figure 5.9. Annual rainfall anomaly, Murray Darling Basin, 1900 to 2008
Source: The Bureau of Meteorology, available at http://reg.bom.gov.au/cgi-bin/climate/change/timeseries.cgi?graph=rranom&area=mdb&season=0112&ave_yr=0.

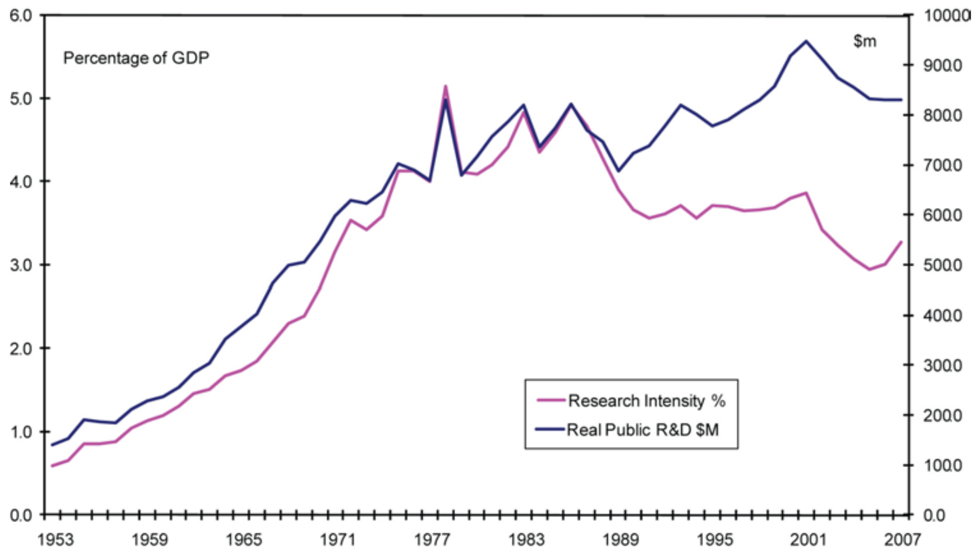

Figure 5.10. Real public investment and research intensity in Australian Broadacre Agriculture: 1953 to 2007 (2008 dollars)
Source: Mullen 2010, derived from public financial statements of public research institutions and the ABS.

1950s and 1960s but has been drifting down from about 4.0%-5.0% annually of agriculture GDP in the period between 1978 and 1986 to about 3.0% per annum in recent years (as compared to 2.6% per annum in developed countries).

Sheng, Mullen, and Zhao (2009) found that based on an analysis of the stability of the MFP index for broadacre agriculture from 1953 to 2007 using the adjusted cumulative sum square index, climate alone did not explain the slowdown in broadacre productivity growth. Rather, the slowdown can be attributed to both poor seasons and the lagged impact of the stagnation in public investment in agricultural R&D since the 1970s.

7. CONCLUSION

MFP in agriculture in New Zealand had been growing slowly relative to the New Zealand economy, but recent estimates from the MAF suggest that this is no longer true. MFP in agriculture since 1988 grew by 2.7% per year and shows no sign of slowing, whereas the MFP growth rate for the economy as a whole was 1.5%.

In Australia, productivity growth in the agriculture, fisheries, and forestry sector has remained strong and shows little indication of slowing. Since 1978 it has grown at a rate of 2.4% per year (using a value-added measure) and has often exceeded growth in the market economy by a factor of 3. Nevertheless agriculture's share in the economy's GDP has continued to fall, though at a slower rate in recent decades. It seems likely that productivity growth in agriculture has been faster in Australia than in New Zealand.

Productivity growth in broadacre industries, on the other hand, while strong to 1998, has been negative in the 10 years leading up to 2007 (-1.4%). Reconciling the ABS and ABARE measures is difficult because the industry coverage is different and the ABS reports a value-added measure for the sector as a whole whereas ABARE reports a gross output–based measure for broadacre industries. Value-added measures exceed gross output measures to the extent that, for the period 1995 to 2004, the growth rate for the ABS series, when converted to an equivalent output-based measure, was similar to the ABARE measure.

Prior to the poor seasonal conditions since 1998, MFP in the broadacre industries was growing at a rate of about 2% per year. Hence, it seems likely that MFP growth in the agriculture, fisheries, and forestry sector also grew at about this rate in terms of an output-based measure and that it continued to grow at about this rate through to 2007.

The performance of industries within the broadacre grouping is diverse. Since 1978, MFP for cropping specialists grew at a rate of 2.1% per year on average but in some subperiods it grew at a rate approaching 5%, and after 1998 it decreased at 2.1% per year. Long-term average MFP growth for livestock specialists was much lower than for crop specialists; however, this trend appears to have reversed for the past 10-15 years. Generally within these industries, output has grown while labor and capital use has been static or declining, with partial productivity measures for these inputs rising. However, for cropping there was a large increase in the use of purchased inputs (4%).

The better performance of cropping specialists and their increased use of purchased inputs is likely explained by a switch toward reduced-tillage cropping also associated with more diverse cropping rotations and greater opportunities to exploit available soil moisture (as opposed to fixed rotations and fallows). Scale economies have likely been an important source of productivity growth in broadacre industries, particularly among crop specialists. Livestock specialists seem to have less scope to switch between enterprises in response to changing economic and climate conditions.

MFP growth in dairying was 1.2% per year over the 1989-2007 period with output growing at a rate of 5.9% per year and inputs growing at a rate of 3.9%

per year, a different experience from broadacre agriculture. The dairy industry has responded to significant deregulation of marketing (particularly since July 2000), with small farms leaving the industry and the remaining farms growing in size and intensity.

An obvious reason for the slowdown in MFP growth for cropping specialists, and broadacre industries more generally, has been the run of poor seasons. Rainfall in the Murray Darling Basin has been below the average for the 1960-1990 period for the eight years starting in 2001.

Public investment in agricultural research has also stagnated since the 1970s. There is a long lag between investment in research and increased productivity on farms. There is concern that this stagnation in investment is now being reflected in the downturn in MFP.

Recent econometric research to disentangle climate and investment factors confirms that there has been a slowdown in broadacre MFP growth and that slowdown can only be explained by the effects of both poor seasons and declining public investment in R&D, not by either of these singly. Australian agronomists are confident that good research opportunities remain to develop technologies that will advance the growth of MFP in Australian broadacre agriculture.

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CHAPTER 6

The Shifting Patterns of Agricultural Production and Productivity in Canada

Terrence S. Veeman and Richard Gray

1. INTRODUCTION

Canadian agriculture has been substantively transformed over the past century. In absolute terms, agricultural production has increased considerably over time. For example, the production of wheat, a major Canadian crop, based initially on the improved variety Marquis, tripled from 1908 to 2008 (Statistics Canada 2009). New crops, such as canola on the Prairies and soybeans in Ontario, have captured significant acreage. The livestock numbers have greatly increased since World War I, the number of cattle and calves nearly doubling, the number of pigs growing about fourfold, and the number of chickens tripling (Statistics Canada 2009).

In relative terms, however, primary agriculture's share of the Canadian economy has shrunk to account for 1% to 2% of gross domestic product and some 2% of national employment. Such structural change has been common in developed nations. Agriculture's role in the economy overall is, of course, somewhat larger if the related input- and output-processing industries of the entire agricultural and agri-food system are considered.

Associated with economy-wide changes in the structure of agriculture, agricultural productivity has increased considerably over time, whether measured

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in terms of increases in crop yields, livestock yield gains, or estimated growth in agricultural total factor productivity. For instance, during the previous century, as a result of crop breeding, increased use of agro-chemicals, and improved practices and technology, the crop yields for wheat, barley, oats, and grain corn grew moderately, leading each of these to more than double (Statistics Canada 2009). Similarly, cattle carcass weights and piglets per sow have risen over time because of improved genetics and management. More specific estimates of overall total factor productivity growth suggest that agricultural productivity in Western Canada increased by more than 1.5% per annum from 1940 to 2004, with crop productivity growth considerably outdistancing livestock productivity growth in much of this period, but not since 1990 (Stewart 2006).

1.1. An Overview of Canadian Agriculture

Nearly 40% of Canadian farms are designated as crop farms, followed in importance by beef farms, which comprise 26.6% of all farms. However, the mix of agricultural commodities varies across the country (AAFC 2005). Production of red meats, along with dairy, is most important in Ontario and Quebec. Red meats, grains, and oilseeds typically account for over 80% of market receipts in the Prairies. In British Columbia, where a range of commodities is produced, fruits and vegetables are somewhat more important, whereas in Atlantic Canada, potatoes and dairy predominate. In 2006, nearly 7% of the farms in Canada reported growing organic products for sale, but only one-quarter of these farms were actually certified.

Agriculture uses only 7% of Canada's land mass and is concentrated in the southern portion of the country, chiefly in the Canadian Prairies and the southerly reaches of Ontario and Quebec. The current Canadian farmland area of 67.8 million hectares has remained relatively constant since World War II, although the land area in crops has crept upward to some 36 million hectares (Statistics Canada 2007). Other significant land-use changes include continuing decline, for more than three decades, in the area of summer fallow and an increase in improved (versus unimproved) pasture. In Western Canada there has been a significant move away from cereal-crop rotations that primarily included wheat and barley, to rotations that include more broadleaf crops such as oilseeds (chiefly canola) and pulse crops (such as field peas and lentils). In terms of cropped area, King Wheat continues to retain the crown, with spring wheat still leading planted acres. This is followed by hay and other fodder crops, with canola now ahead of barley in third place as the second most important cash crop. Since

1990 farmers have also adopted no-till farming techniques, and no-till acreage now covers roughly half the crop area.

Beef production shifted somewhat from eastern to western Canada, and the Prairie region experienced the largest growth in pig production, at least until 2006. Farm size has also increased in terms of herd size; from 1971 until 2001, the average number of cows per dairy farm more than tripled, while the number of pigs per hog farm rose by more than 10-fold (AAFC 2005). But the cattle and hog sectors have experienced considerable structural change, especially in hogs, with falling farm numbers but rising animal numbers. The number of farms reporting cattle and calves dropped 41% between 1981 and 2006, while cattle numbers rose to 15.8 million by 2006 (Mitura 2007) but declined thereafter. Beef cattle production became increasingly specialized into two distinct operations: cow/calf ranching and cattle feedlot finishing. The majority of beef cattle farms—some three-quarters—are now cow/calf operations. The number of farms reporting hogs decreased greatly from 1981 to 2006, dropping 80% to only 11,500 farms, each with an average of 1,162 pigs. In 1992 Canada had 31,200 dairy farms with an average herd size of 44 cows. By 2008, the number of dairy farms in Canada had decreased by 56.5%, to 13,587 dairy farms, with an average herd size of 67 cows. These trends were evident in the latest Census of Agriculture (2006) with fewer and larger farms in Canada recorded, reflecting continuing consolidation and specialization in Canadian agriculture. The number of farms had dropped to 229,000, continuing the steady decline since 1941 (Statistics Canada 2007; Mitura 2007). Average farm size recorded in the 2006 Census was 295 hectares. This average, of course, masks considerable differences across Canada, ranging from more intensive 100-hectare farms in Central Canada (Ontario and Quebec) to more extensive farms in Saskatchewan, which average nearly 600 hectares in size (AAFC 2007).

Agricultural production, as in the United States, is increasingly concentrated on larger farms. In 2005, there were some 5,900 "million-dollar" farms (with gross farm receipts exceeding this figure), representing only 2.6% of all farms in Canada and earning nearly 40% of total receipts. In contrast, the farms with less than Can$100,000 in farm receipts comprised 65.6% of all farms and generated only 9.9% of all farm receipts (Mitura 2007).

Concurrently, farm operators in Canada are an aging demographic, now averaging 52 years of age (Statistics Canada 2007). Fewer young farm operators are being attracted to and retained in the industry. Some 28% of the 327,000 farm operators recorded in the latest (2006) census were women. Increasingly the economic well-being of farm households is linked to the nonfarm economy, with nearly half of all farms reporting off-farm income (Mitura 2007). Further, for unincorporated farms in 2006, off-farm income from all sources was four times as important to farm family income as net operating income from farming (AAFC 2009). In terms of operating arrangements, 57% of Canadian farms were sole proprietorships, 27% were partnerships, and 16% were incorporated. This corporate share has been rising, but an important distinction is the fact these "corporate" operations are still largely family incorporations.

Trade, particularly with the United States, is very important to Canadian agriculture. The red meat sectors became increasingly integrated within the North American market in the past 15 years. Some 70% of Canadians' food purchases are produced domestically, with the United States providing 57% of Canada's food imports (Statistics Canada 2009). Further, slightly over half of Canada's food exports go to the United States. Canadian farm producers are more export-dependent than American or European producers. Canadian grain and oilseed farmers have long relied on export sales, and red meat producers are increasingly export oriented (AAFC 2005).

1.2. Crops and Livestock in Canada: Shifting Patterns over Time

Canada is ranked eighth in world cereal production and tenth in world meat production (Statistics Canada 2009). During the decade from 1999 to 2008, on average about 48% of total farm cash receipts in Canada came from livestock receipts, some 41.3% from crop receipts, and the remaining 10.7% from government program payments (CANSIM Database).[1] The changing relative importance of these three major shares (crops, livestock, and direct payments) from 1971 until 2008 is illustrated in Figure 6.1. Livestock receipts, at roughly half the total, have generally exceeded crop receipts over this period, with 2007 and 2008 being recent notable exceptions, associated with stronger grain prices and adverse fortunes for red meat producers. Government payments have tended to increase, often on an ad hoc basis, in years of drought, animal disease, border problems, and financial stress.

Some features of the changing crop acreages over time have already been mentioned. It is also of interest, and even more revealing, to examine the chang-

[1]Note that indirect transfers from consumers, arising from Canada's supply management systems for dairy and poultry products, are reflected in the receipts for these sectors.

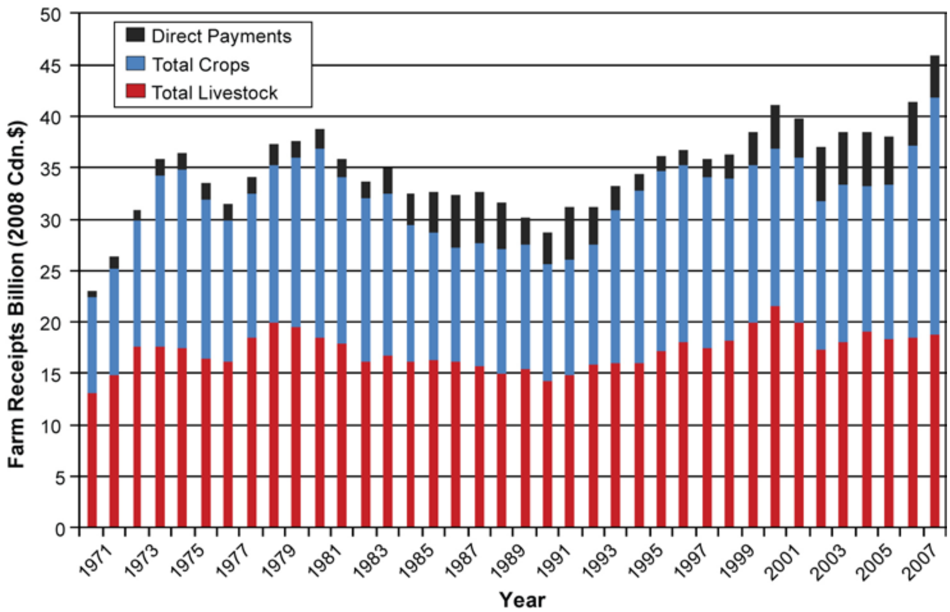

Figure 6.1. Shares of total farm cash receipts from crops, livestock, and direct payments, Canada, 1971-2008

Source: Authors' calculations from CANSIM Database.

ing pattern of crop receipts over time, as shown in Figure 6.2. The large share of the "other crops" category (which had been rising, at least until 2004) reflects the wide range of crop commodities grown across Canada and the increasing diversification of Canadian crop production. The considerable relative decline of wheat (excluding durum) as a source of farm crop receipts is clearly evidenced in Figure 6.2. Similarly, the significant relative rise in canola receipts and the relative decline in barley are portrayed. Corn and soybeans have both risen in relative importance, but they still only contribute approximately 6% and 5%, respectively, to Canadian crop receipts. Corn for biofuel production is not currently significant in Canada.

The relative breakdown of livestock receipts in Canada from 1971 to 2008 is shown in Figure 6.3. In the last decade of this period, cattle and calves contributed nearly 33% of total livestock receipts in Canada, with hogs providing 19%, dairy 26%, and chickens and hens 9%. The share of receipts from cattle and calves has dropped somewhat over time (especially since 2002) while the hog share of total livestock receipts increased from the 1990s until 2004 but sharply dropped thereafter.

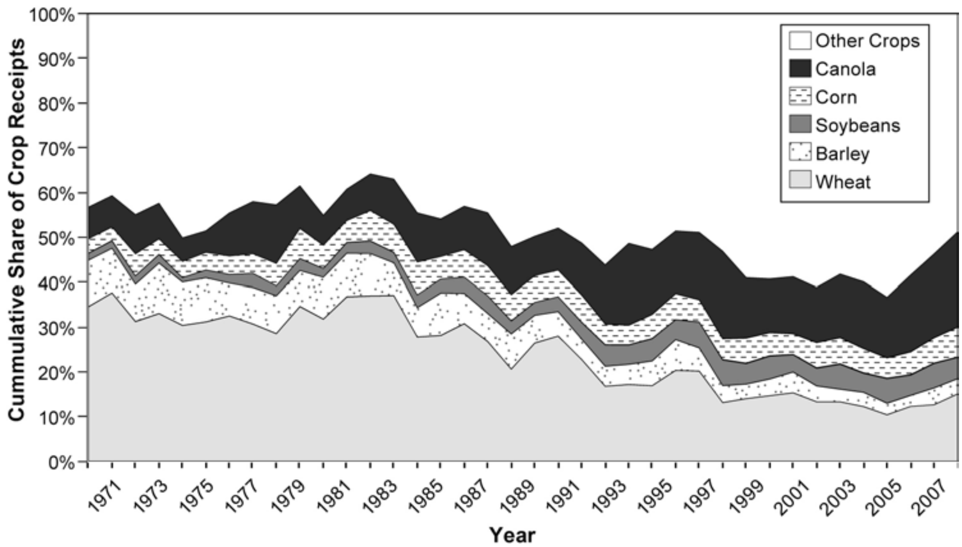

Figure 6.2. Shares of total crop receipts by individual crops, Canada, 1971-2008

Source: Authors' calculations from CANSIM Database.

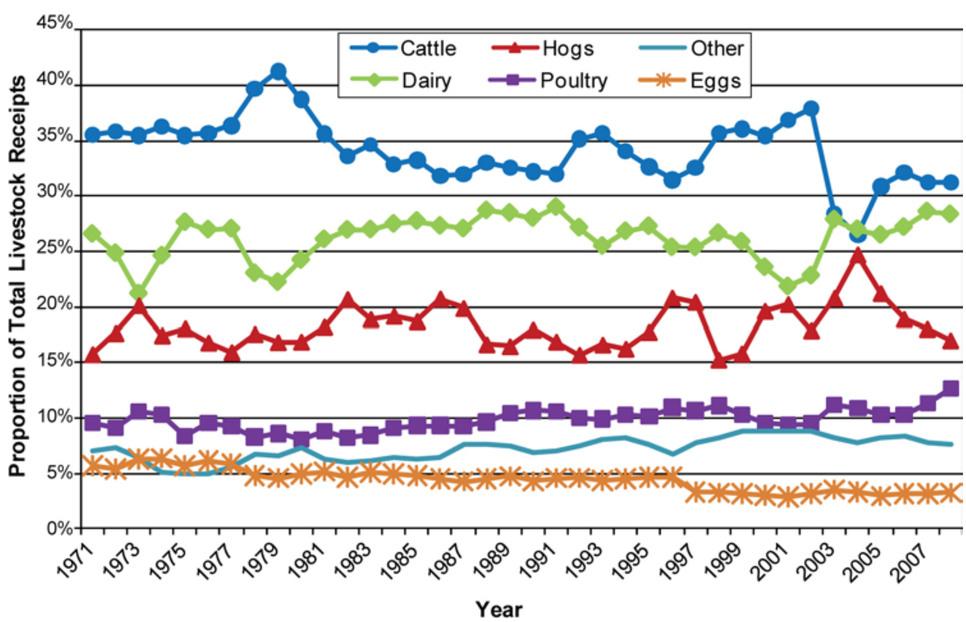

Figure 6.3. Shares of total livestock receipts by individual livestock categories, Canada, 1971-2008

Source: Authors' calculations from CANSIM Database.

1.3. Key Socioeconomic Factors Underlying These Changes

Many factors underlie the changes in Canadian agriculture and its crop and livestock production, and of these, only a few can be briefly highlighted. On the demand side, declining responsiveness of demand to global income growth (reflected in Engel's Law) has been important for many agricultural commodities, particularly for food staples such as wheat. Red meat demand and production have seen negative influences, from shifts in domestic consumers' preferences toward chicken and fish, and positive influences, as Canadian red meat production increasingly became integrated into the North American market (subject, of course, to market access at the border). On the supply side, Canadian agricultural production has been subject to the pervasive historical forces of capital-for-labor substitution and technological change. Crop production has become increasingly consolidated into large-scale farming operations, especially in Western Canada. Over time, most Canadian red meat production, particularly cattle feeding and hog production, has also become increasingly concentrated in intensive livestock operations.

2. PARTIAL PRODUCTIVITY MEASURES FOR CANADIAN AGRICULTURE

The Canadian agricultural sector has changed significantly in many ways during the past 50 years. Despite long-term declines in globally determined real prices the output of the sector has increased through improvements in productivity, which have lowered the cost of production. In this section we examine some partial measures of productivity improvement and describe some of the changes in technology that have contributed to productivity improvement. Changes in total factor productivity for Canadian agriculture are reported in the third section of this chapter. The remainder of this section is organized in two parts, each representing an important aspect of productivity improvements. The first part describes crop yields and changes in the crop sector over time, while the second describes changes and productivity gains specific to the livestock sector. Changes to labor productivity that are common to both crops and livestock in the Canadian context are briefly discussed in a subsequent section in which total factor productivity growth rates, from Statistics Canada time-series data, are introduced and compared.

2.1. Crop Yields (Land Productivity)

Changes in crop yields are the most readily available measures of productivity gains in Canadian agriculture. In Canada and elsewhere, slowly increasing crop yields have allowed the sector to feed a growing population on a relatively finite land base. As shown in Figure 6.4, the yields of the major field crops grown in Canada, (wheat, barley, canola, corn, soybeans, and peas) all increased from the 1960s until the present. Several features are noteworthy, including the volatile nature of yields even at the national level, highlighting the important continuing role of weather in influencing annual yields. Further, indexed against a base of the 1960-64 average, yields of all these crops follow a similar trend, increasing by about 60% during the 47-year period, to the point that statistical testing could not reject an identical linear trend coefficient for corn, wheat, canola, and peas.[2] This is remarkable considering the varying locations, biological properties, farming systems, and research institutions associated with each crop. The linear trend suggests a constant absolute growth in yields, which implies a declining proportional growth rate, since the same absolute increase per year is a smaller percentage of the growing base—in fact, a 60% decline in the proportional rate of growth over the period.

The yields shown in Figure 6.4 are based on yield per seeded acre and do not reflect changes in cropping intensity that have occurred in Western Canada,

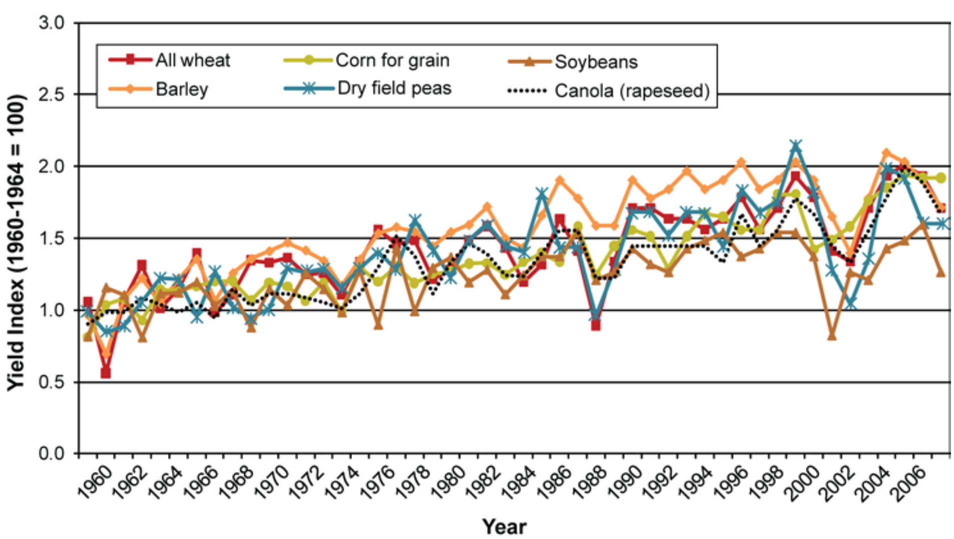

Figure 6.4. Canadian crop yields, 1960-2007 (base 1960:1964 = 100)

Source: CANSIM Database.

[2]Yield index data (1960-64 =100) were pooled and each index was estimated as a simple linear function of time. A cross-equation restriction that all trends were equal across crops could not be statistically rejected, with the exception of soybeans, which had a slower trend.

which have been a major factor in increased productivity within the crops sector. During the 1960s summer fallow was a dominant cultural practice in much of Western Canada. In a summer-fallow rotation the land is left fallow for 18 months after harvesting a crop, and weeds are controlled by tillage or herbicides for the summer in between cropping years. While this practice releases nitrogen from the soil organic matter and accumulates more moisture in the soil, it also reduces cropping intensity by postponing production by an additional year. As a result of the decline in summer-fallow area, annual cropping intensity in Western Canada has increased from 62% to 87% of cultivated area. If this increase in cropping intensity was reflected in yields, the yield growth per cultivated area of wheat, barley, canola, and peas would be closer to 100% over the 47-year period.

In contrast to trends in actual farm crop yields, acreage-weighted research trial yield indexes diverge markedly among Canadian crops (Figure 6.5). Both wheat and durum yields in experimental trials[3] exhibited slow linear trends, increasing to 122% of the 1960-64 base yield over the period to 2006. Canola yields in experimental trials grew rapidly until 1972, but this growth was reversed from 1975 to 1983 as canola, with low glucosinolate and low eurcic acid replaced rapeseed, with the accompanying yield drag of any major crop transformation. Canola trial yields then increased significantly from 1986 to 1994, only to retreat in the late 1990s as herbicide-tolerant varieties were adopted, with major agronomic benefits to growers in terms of weed control but again with the accompanying yield limitations of a major change in the available varieties. Since 1998, canola yields have again grown rapidly, as hybrid varieties have been developed and widely adopted.

In experimental trials, pea yields tracked wheat yields until 1994, but since 1994 pea yield growth has accelerated significantly. The period of rapid trial yield growth for peas corresponds to the pea research output of the Crop Development Center, which is funded by research check-offs from Saskatchewan pulse growers. The cumulative result of these changes is that, compared with the base yield indexes in 1960, in 2006 the canola yield index was 180%, the peas index was 148%, and the wheat and durum yield indexes were just over 120% of the base.

The contrast between the growth patterns in the acreage-weighted experimental yield indexes and the Canadian average realized yields of these various

[3]New varieties of grain are tested in experimental cooperative trials that use side-by-side comparisons with established varieties to establish a yield index of each new variety.

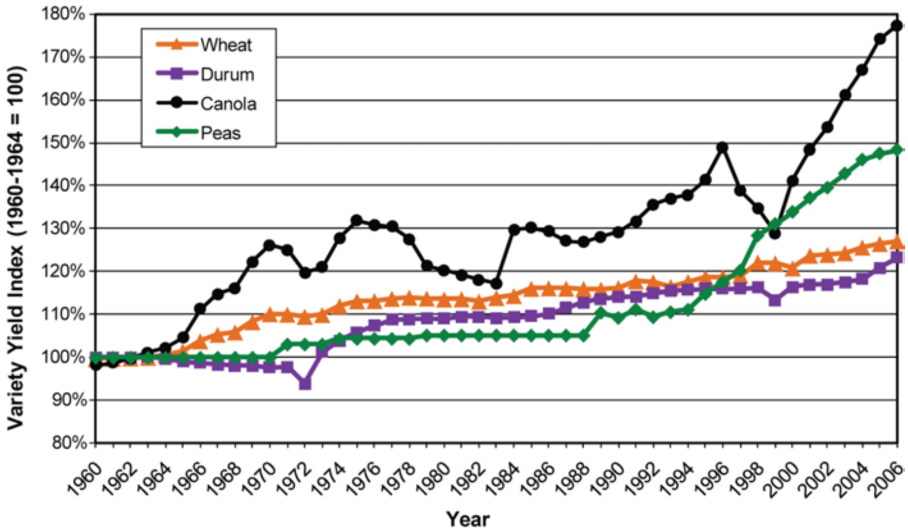

Figure 6.5. Research trial yield indexes for selected Canadian crops, 1960-2006 (1960-1964=100)

Source: Authors' calculations based on research trial data and seeded area.

crops is most intriguing. Despite very different patterns of growth in experimental yield indexes across crops, the trends in the actual farm crop yields of peas, wheat, and canola could not be statistically distinguished from each other. One could speculate that changes in seeded area and disease pressures have caused convergence in the actual crop yields. Further analysis is needed to reconcile the differences between the experimental yield indexes and the patterns in Canadian average realized yields of various crops.

Important quality changes, which increase value but are not captured in the yield figures, have also occurred for many crops. Spring wheat varieties were confined to hard red spring wheat in the 1960s. While hard red spring wheat still dominates planting, new classes of wheat have been introduced over time, with each wheat class made up of varieties that can be visually distinguished from other wheat classes. Durum wheat now includes extra-high-gluten varieties. Even hard red spring wheat has seen some quality attributes such as protein levels reflected in payment premiums. Canola was transformed from rapeseed in the early 1970s by reducing the level of glucosinolates and erucic acid. Since 2000, new canola varieties high in oleic acid have been introduced. The pulse industry has introduced a wide variety of new types of lentils, chickpeas, and field peas, in some cases targeting high-value niche markets. While feed is the primary use of barley, plantings continue to be dominated by two-row malting varieties, which replaced earlier six-row malting varieties.[4]

The balance of types of crops grown has shifted significantly since 1960. In particular, farmers in Western Canada have moved from a wheat, oats, and barley cereal monoculture to more robust rotations that include broadleaf crops such as canola and pulse crops, while farmers in Ontario and Quebec have introduced soybeans into their rotations. The magnitude of these changes is illustrated in Figure 6.6, using the percentage of acres seeded to non-cereal crops as a measure of diversification.

Discussion of productivity enhancement in cropping systems would be incomplete without mention of the dramatic change in tillage systems (Zentner et al. 2002). In the 1960s, fields were tilled extensively during the summer-fallow period in much of Western Canada and tilled again prior to seeding. In the more-humid regions of Central Canada, land was tilled with a moldboard plough to bury the stubble residue from the previous crop. While these intensive tillage practices

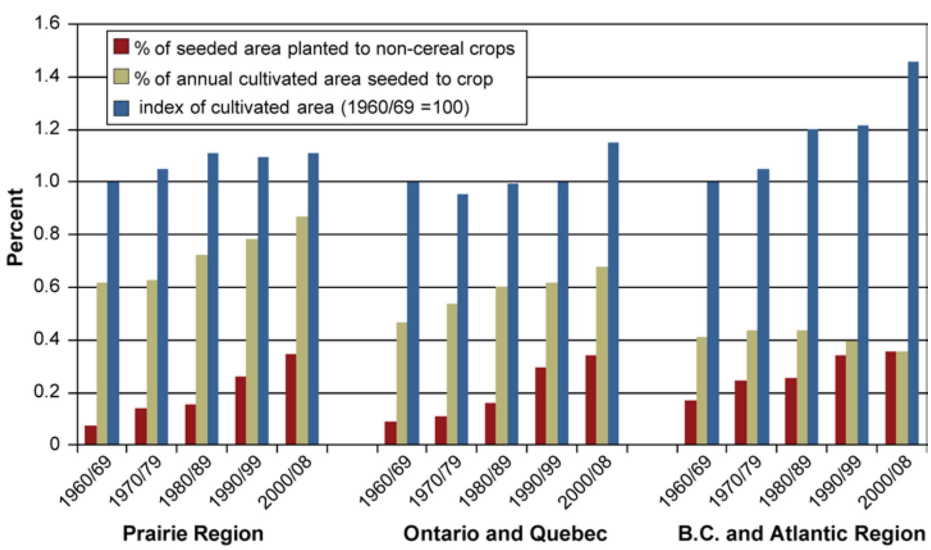

Figure 6.6. Land use cultivated and seeded area and diversity of crops, selected regions of Canada by decade, 1960-2007

Source: Authors' calculations from CANSIM Database.

[4]Farmer and research preoccupation with malting varieties has often been alleged as a reason why barley yields have not advanced as rapidly as they might have, had more attention been placed on the breeding and growing of superior feed barley varieties (see Ulrich, Furtan, and Schmitz 1986).

controlled weeds, they also contributed to soil erosion and a general loss of soil organic matter. Beginning in the 1970s, some farmers and industry groups began developing seeding systems and weed control systems that required less tillage. By the 1990s, very effective low-disturbance seeding systems had been developed, and they were rapidly adopted, as illustrated in Figure 6.7. All areas of Canada are adopting reduced-tillage systems, with the highest adoption rates occurring in Saskatchewan. These cropping systems reduce the demand for diesel, fuel, and labor, while increasing the demand for glyphosate herbicide and nitrogen fertilizer.

The adoption of low-disturbance seeding systems and the introduction of more intensive, and diverse crop rotations have also had a significant impact on the environment. These systems have reversed the long-term decline in soil organic matter and have resulted in a significant amount of carbon sequestration in the growing pool of organic matter. The reduction in tillage has significantly reduced both water and wind erosion. To the extent these environmental benefits are excluded in productivity measurement, the recent gains in productivity are understated.

Finally, it is important to note that the impact of changes in yield, cropping intensity, cropping diversity and tillage systems on productivity cannot be easily separated from one another. Each of these aspects of the cropping system has complemented the others. Similarly, a better use of available moisture has reduced the need to summerfallow, while increasing the demand and opportunity

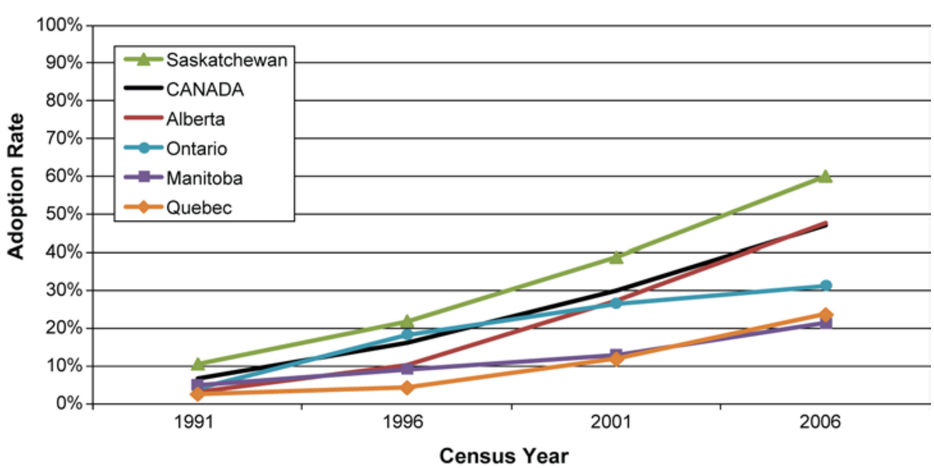

Figure 6.7. Adoption of low-disturbance seeding as a percentage of seeded area, Canada and selected provinces

Source: Statistics Canada, Census of Agriculture, 1991, 1996, 2001, 2006.

for growing other crops in the rotation. The access to higher-yielding pulse and canola crops has made these rotations more attractive.

2.2. Livestock Partial Productivity Measures

Livestock yields have risen over time as a result of improved genetics, feed conversion, and management practices, as well as the exploitation of economies of scale in production. In recent years, as noted, Canada's livestock industry has shifted toward more intensive livestock operations with a much smaller number of farms (except for the supply-managed poultry sector), an increase in the number of animals per farm, and many productivity-related improvements. For example, in Ontario, the efficiency of feed conversion for most livestock operations is estimated to have tripled between 1950 and 2000. Given that the yields per acre of feed grains doubled in Ontario in this period, each acre could effectively support six times as much livestock production in 2000 as in 1950 (White, Dalrymple, and Hume 2007).

In the case of cattle, beef production per cow has risen from about 170 kilograms in 1972 to approximately 272 kilograms in 2006. As well, during the 23-year period from 1980 to 2003, cattle carcass weights increased by 34% (AAFC 2005). Hybrid vigor from crossing traditional with newer European breeds was a major factor in this improvement. There are no Brahma or Cebu breeds in Canada's beef herd, unlike arid regions of Australia or the United States, so Canada has no concerns about reduced meat tenderness from this factor.

The Canadian hog industry has experienced notable productivity improvements arising from new genetics, new technologies, and economies of scale. Following the trend in other nations, Canada has seen the benefits of increased production from monogastric animals, such as hogs, which can utilize concentrated feeds very efficiently and which have shorter life cycles that foster faster genetic advance. From 1990 to 2003, larger litter sizes, more litters per year, and heavier carcass weights resulted in a 38% rise in production per sow (AAFC 2005). Genetic improvement in swine is reflected in the reduction in age at which hogs in Ontario reach 100 kg, which fell from 183 days in 1980 to 157 days in 2006 (White, Dalrymple, and Hume 2007). Despite the major advances in Canadian hog production and productivity up to 2006, the hog industry has been struggling economically since then, citing problems with global demand, trade barriers, and environmental constraints.

The Canadian dairy industry has also experienced some structural change and productivity increases. Increases in milk production per dairy cow have accompanied the increase in herd size. In 1991-92, milk production per cow was 5,456 kg whereas by 2007-08, average milk production per cow was 9,538 kg, representing almost a 43% increase in productivity from 1991 to 2007, an increase of 2.5% per year during this period (Canadian Dairy Commission 2009).

The poultry industry also changed structurally, with farm size increasing 35% from 1990 to 2007. In contrast to other sectors, the number of chicken producers increased slightly during this time period (Chicken Farmers of Canada 2009). Broiler chicken production experienced remarkable changes in productivity, as feed conversion rates improved sharply and the number of days for a broiler to reach market weight fell dramatically. Despite significant prior gains, the average number of eggs per layer has remained fairly stable since 1990, ranging from 265 to 270 eggs per year.

3. TOTAL FACTOR PRODUCTIVITY MEASURES AND GROWTH RATES FOR CANADIAN AND PRAIRIE AGRICULTURE

Partial productivity measures such as yield per unit of land can certainly be informative and useful, as we have seen in the preceding section. However, a better indicator of productivity performance, if it is available, is total factor productivity (TFP), particularly where substantial input substitution is occurring over time. TFP or multifactor productivity is the ratio of aggregate output to aggregate input, wherein as many inputs in the production process as possible, and not just a single input, are counted in evaluating productivity performance. TFP growth, then, is the growth in aggregate output that is not explained by growth in all measured inputs (for example, land, labor, capital, and materials).

3.1. Total Factor Productivity Growth in Canadian Agriculture

There is modest historical literature on productivity growth in Canadian agriculture. However, the extensive body of agricultural-specific productivity analyses undertaken in the United States has not been replicated in Canada at the national level. Some useful empirical information on TFP in Canadian agriculture does exist as an ancillary product of the extensive work on productivity in the Canadian economy and its sectors undertaken by Statistics Canada, especially in the past decade.

In CANSIM Table 383-0022, Statistics Canada provides time-series data relating to agriculture, from 1961 to 2005, on TFP based on gross output, TFP based on value added, and labor productivity. The most appropriate agriculture-related output variable available for our analysis is the combined crop and livestock production index. Over the period 1961 to 2005, TFP (based on gross output) for crop and animal production in Canada increased by 0.6% per year. Over the same time period, TFP (based on value added) for crop and animal production grew somewhat more rapidly, at some 1.4% per year. Following Christensen (1975), we prefer TFP measures based on gross output rather than on value added. However, the productivity growth rate estimate based on the preferred measure is appreciably lower than the estimates of agricultural productivity found in prior studies of the United States, the Canadian Prairies, or Australia. One possible reason why the growth rate in TFP reported by Statistics Canada based on gross output is comparatively low is that the annual compound growth rate for all inputs combined in crop and livestock production based on Statistics Canada's evidence is 2.4%, a rate considerably higher than in comparable American and Australian studies for aggregate input use in agriculture.

Finally, labor productivity in Canadian crop and animal production grew even more rapidly from 1961 to 2005, at 4.7% per year. Indeed, labor productivity growth in agriculture has tended to be considerably faster than in other sectors of the Canadian economy. However, the concern is that labor productivity growth considerably overstates the total overall productivity gains in agriculture, given the substantive increases in the use of material inputs and the historical capital-for-labor substitution in production.

3.2. Productivity (TFP) Growth: The Case of Prairie Agriculture in Western Canada

The Prairie provinces of Alberta, Saskatchewan, and Manitoba are the "bread basket" of Canadian agriculture, comprising nearly half of Canada's farms and much larger shares of its cropland and grassland base. A lengthy time-series study of productivity growth in Prairie agriculture, using TFP measures based on Tornqvist-Theil indexing procedures, was recently completed (Stewart 2006). Using this detailed case study, we can focus on the estimates of output, input, and productivity growth for Prairie agriculture from 1940 to 2004, including the disaggregation of the analysis to the crop and livestock sectors (Stewart, Veeman, and Unterschultz 2009; Veeman, Stewart, and Unterschultz 2006). We can also assess how and why productivity growth has occurred.

3.2.1. Prairie Agricultural Production over Time

The measurement of productivity growth in Prairie agriculture requires the construction of a comprehensive and lengthy data set of both quantities and prices for agricultural inputs and outputs. Beyond its use in measuring productivity growth, the data set also points to overarching trends in Prairie agricultural production over 65 years. In terms of input use, technological change in Prairie agriculture has been strongly labor saving and materials using. This is a reflection of the rapid mechanization of agriculture, gains in labor productivity, and the increasing use of pesticide, fertilizer, and energy inputs.

Agricultural outputs have also changed substantially over time. The Prairie crops sector typically produces in excess of 60% of the total value of Prairie agricultural production, although the livestock sector increased its share of total agricultural production from the 1980s onward. As evident in Figure 6.6, there has been a decline in the share of cereal crops being produced (e.g., wheat, barley, and rye) and an increase in production of canola and specialty crops (e.g., lentils, peas). Barley, until lately, nearly retained its share, and tame hay increased its share, principally as feed for the growing Prairie livestock sector.

Cattle's share in total Prairie livestock production increased from 1940 until 1980, as a feed lot industry was established in southern Alberta. By 1980 cattle's share began to stabilize, and then it declined somewhat as swine production expanded rapidly (principally in Manitoba). The cattle share also declined substantially following the 2003 finding of BSE in an Alberta cow and subsequent international trade restrictions. Poultry and dairy's share of livestock production declined relatively steadily from 1940 to 2004.

3.2.2. Prairie Productivity Growth and Its Measurement

Törnqvist-Theil indexes were employed to obtain the estimates of output growth, input growth, and TFP growth presented in Table 6.1. This "superlative" indexing methodology has been widely used since the 1970s (Christensen 1975), subject to the availability of data (notably input price data).

Considering average growth rates, computed as compound annual rates of growth by fitting trends to the respective underlying index numbers, Prairie agriculture displayed relatively strong overall productivity and output growth of 1.56% and 2.43% per annum, respectively, over the period 1940 to 2004 (see Table 6.1). Aggregate input growth is more modest at only 0.86% a year. Accordingly, productivity growth (on a gross output basis) accounts for the lion's

Table 6.1. Average annual compound percentage growth rates for Prairie aggregate agricultural inputs, outputs, and productivity (TFP), 1940-2004

	1940-2004	1940-1959	1960-1979	1980-2004	1990-2004
TFP growth	1.56	1.25	1.48	1.80	1.46
Input growth	0.86	-0.03	1.45	0.57	0.21
Output growth	2.43	1.22	2.95	2.38	1.67

Source: Stewart 2006.

share of the considerable growth in Prairie agricultural output over this 65-year period. However, growth rates measured over various subperiods indicate substantial variation over time. Of particular significance is the decline in productivity growth over the 15 years prior to 2005, and the associated decline in output growth, partly but not solely due to the bad drought years of 2001 and 2002. Other factors may include the emergence of new disease and pest pressure such as fusarium head blight and wheat midge, and major cultural changes such as the widespread adoption of zero tillage. The historical trends of Prairie agricultural output, input, and productivity growth over time are shown in Figure 6.8. The considerable year-to-year variations in output and productivity growth are largely associated with weather and climatic factors, chiefly summer (June and July) rainfall and temperature, as was noted in the prior discussion of crop yield variation.

To assess the aggregate productivity growth measures in more detail, estimates are also obtained at the provincial and sectoral (i.e., crops and livestock) levels. Census data information is used to allocate shared inputs between the crops and livestock sectors, with shares being interpolated for intercensal years. A number of noteworthy trends can be discerned from Table 6.2. First, productivity growth in the crops sector over the 65-year period is substantially (some two to three times) higher than that in the livestock sector, a result also found in the United States (Huffman and Evenson 1993). The stronger growth path of productivity in the Prairie crops sector relative to the livestock sector is also evidenced in Figures 6.9 and 6.10. Second, productivity growth in Manitoba agriculture was considerably higher than in Alberta or Saskatchewan agriculture, and productivity growth in Saskatchewan agriculture was slightly higher than in Alberta agriculture (see Stewart 2006). Third, while crop productivity growth declined considerably over the final 15 years of the study, livestock productivity growth accelerated (at least in Manitoba and Saskatchewan). The slight decline in aggregate Prairie agricultural productivity growth then was the result of slower

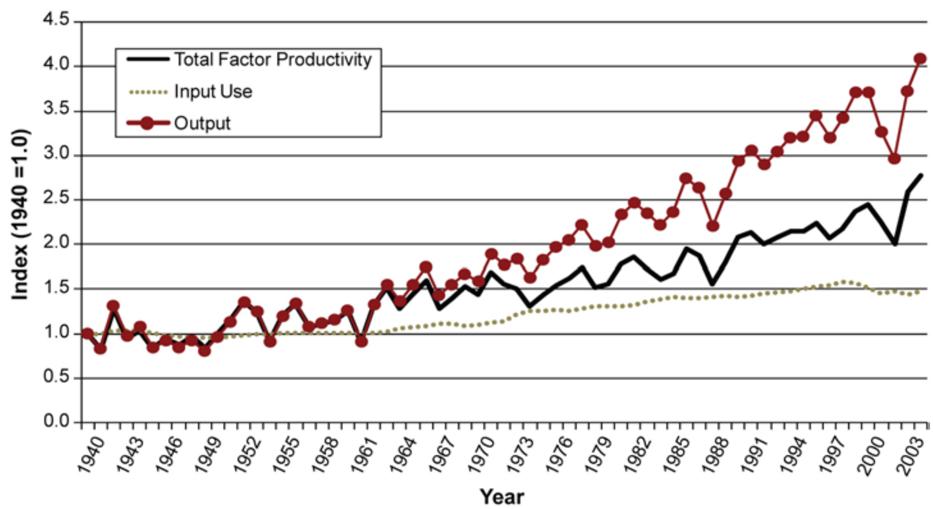

Figure 6.8. Törnqvist-Theil Indexes of Prairie aggregate agricultural inputs, outputs, and productivity, 1940-2004

Source: Stewart 2006.

Table 6.2. Average annual compound productivity percentage growth rates for Prairie provinces by crops and livestock sectors

	Crops		Livestock	
	1940-2004	1990-2004	1940-2004	1990-2004
Alberta	1.65	-0.33	0.54	0.58
Saskatchewan	1.76	0.39	0.59	4.28
Manitoba	2.12	2.70	0.97	5.33
Prairies	1.77	0.51	0.65	2.27

Source: Stewart 2006.

productivity growth for crops, while the acceleration of livestock productivity growth moderated the slowdown in aggregate Prairie productivity.

The stronger productivity performance in the Prairie crops sector from 1940 to 2004 does not mean, however, that the sectoral profitability of the crops sector has been better than that in the Prairie livestock sector. A crude measure of change in sectoral profitably is provided by change in its returns-to-cost ratio (*Py.Y/Px.X*) which, in turn, is the product of TFP (*Y/X*) and the sector's terms of trade (*Py/Px*) where *Y* is aggregate output, *X* is aggregate input, *Py* is the aggregate output price index, and *Px* is the aggregate input price index (Krishna 1982). Because the sectoral terms of trade facing the crops sector has deteriorated more rapidly over time (at –2.57% per annum versus only –0.29% for the livestock sector), the returns-to-

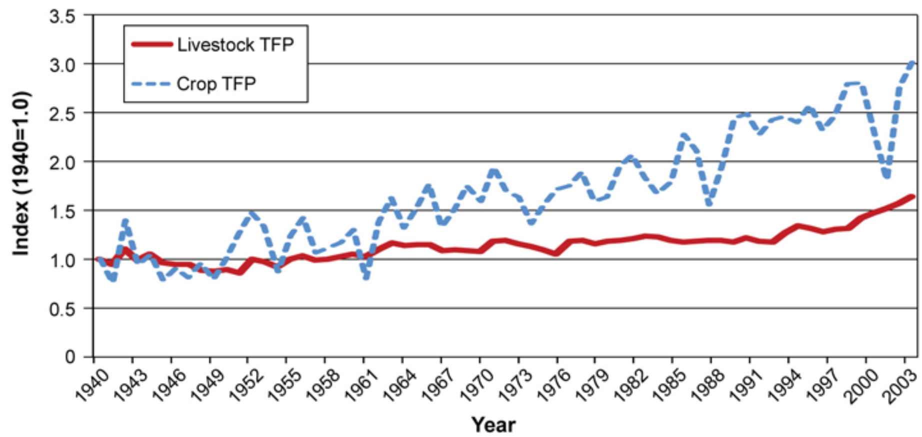

Figure 6.9. Törnqvist-Theil Indexes of crops and livestock total factor productivity for the Prairies, 1940-2004

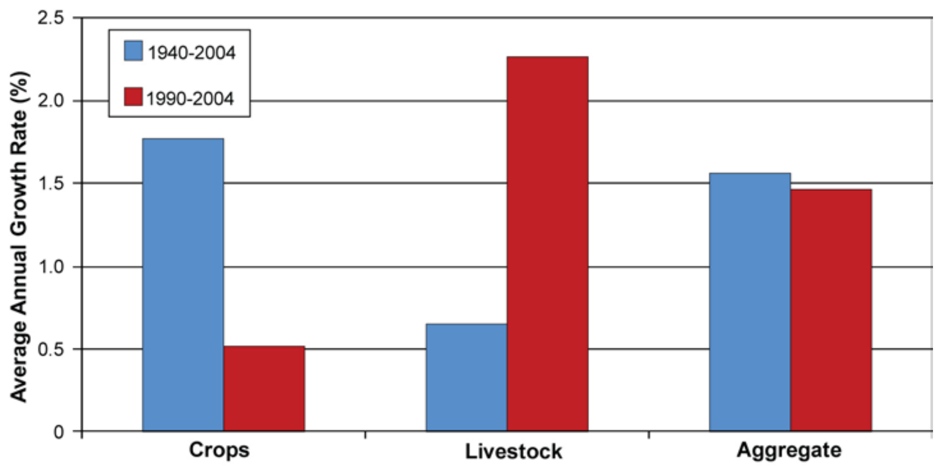

Figure 6.10. Productivity growth rates for the Prairies, 1940-2004 and 1990-2004

Source: Stewart 2006.

cost ratio for the crops sector has declined by 0.85% per year while the same ratio has actually increased somewhat in the Prairie livestock sector, at 0.36% per year over the 1940 to 2004 time period (Stewart 2006). In short, historically, productivity advance has slightly outpaced cost-price squeeze pressures in the livestock sector but has fallen behind in the crops sector on the Canadian prairies. It must be recognized that the terms of trade for prairie farmers is largely influenced by productivity growth outside Canada, which drives relative prices globally, rather than the smaller influence of productivity growth inside Canada.

The relative agricultural productivity growth performance of the three Canadian Prairie Provinces is quite consistent with that of the 10 Great Plains states in the United States, as reported by the U.S. Department of Agriculture online in 2007 (Stewart, Veeman, and Unterschultz 2009). For the comparable period of 1960 to 1999, the average productivity advance in the Canadian prairie provinces of 1.6% per year is only slightly higher than the annual average 1.4% growth rate in TFP in the Great Plains states. Moreover, for the more immediate and shorter time period of 1980 to 1999, the average Great Plains rate of 2.0% per year is very slightly higher than the Canadian prairie rate of 1.9%. A major caveat, however, to this bilateral comparison is that some of the input data, such as labor, are quality adjusted in the work by the U.S. Department of Agriculture for the United States, an adjustment that would lead to somewhat lower productivity growth rates for the Great Plains states.

3.3. How Prairie Productivity Growth Happened

In this section, the empirical results of decomposing estimated productivity growth in the crops and livestock sectors into their constituent parts are very briefly summarized (Stewart 2006; Stewart, Veeman, and Unterschultz 2009). Productivity growth can be ascribed to one of three influences: technical change, increases in the degree of technical efficiency, or greater economies of scale in production. By using a translog cost function, productivity growth can be econometrically decomposed to reveal the respective roles of technology and economies of scale in productivity growth (Capalbo 1988). Efficiency changes are reflected along with measurement errors in the reported residual.

In the case of Prairie agriculture, the crops sector has been better able to leverage productivity growth from technological advances, since for Alberta, Saskatchewan, and Manitoba, respectively, 94.7%, 84.5%, and 80.4% of the recorded productivity growth since 1940 has been generated by technical change (Stewart, Veeman, and Unterschultz 2009). In contrast, the livestock sector has been more effective in generating increasing returns to scale over time, with about half of its productivity advance attributable to scale impacts historically. Accordingly, the recent slowdown in crops productivity growth can be largely attributed to limited technological advances in this sector. The accelerating livestock productivity growth can be attributed in part to technological gains accruing to the sector, but more importantly to the economies of scale realized from the rapid increase in livestock output over the 15 years to 2005 and the increasing shift to intensive livestock operations.

4. PRODUCTIVITY GROWTH SLOWDOWN AND LINKS TO RESEARCH

In this section, we briefly assess whether there has been a recent slowdown in agricultural productivity growth in Canada and in the Prairie region of Western Canada. Linkages of productivity change in primary agriculture to expenditures on agricultural research and development (R&D) are also explored. Whether agricultural productivity growth has slowed down or not in the past two decades is an open question in many nations, Canada included.

Although crop yields are only a partial productivity measure, changes in crop yields provide the most readily available and long-standing measures of productivity gains in Canadian agriculture. As we have noted, aggregate crop yields have followed a linear pattern of growth since the early 1960s such that the proportional rates of growth of the yields of the major Canadian grain and oilseed crops—wheat, canola, corn, and peas—declined over time.

The TFP growth estimates available for agriculture that are most convincing are those for the Prairie region of Western Canada. Structural change (Chow) tests were undertaken for each of the crop, livestock, and aggregate (multioutput) agricultural productivity growth for this region to see if a structural break occurred in 1990. Such a structural break is statistically confirmed for livestock productivity growth, with the rate of growth being faster after 1990. For crops productivity, the rate of growth is lower after 1990, but this is not statistically significant. It is possible that the shift to zero-till and greater cropping intensity partially compensated for the declining yield growth rates in crops. For crops and livestock taken together, the rate of productivity growth is actually higher after 1990, but the structural break is not statistically significant.

If a productivity slowdown has occurred in the past two decades in Canadian agriculture, this has occurred in the crops sector. The evidence for this is most convincing from the crop yield trends, and somewhat less so for TFP growth in crops grown in Prairie agriculture. Complicating the assessment overall of recent productivity trends is that the year 2008 saw record or near-record crop production levels and yields in Canada but continuing poor economic and financial conditions for the red meat sectors.

There is reasonable qualitative evidence and some econometric evidence to support the view that lagging agricultural R&D is adversely influencing agricultural productivity growth, especially in crops. Real public agricultural research expenditures in Canada for both crops and livestock declined between 1996 and 2004 (Gray 2008). The impact of variety improvement is most apparent in wheat, for which there has been little private research activity. The extent that canola and pea variety improvement may have recently accelerated has been offset by other factors in production, as historical average yields follow strikingly similar linear growth patterns across all major crops. Specific explanations for productivity growth and its variability over time among provinces and between the livestock and crop sectors can be advanced for Prairie agriculture (Stewart 2006). Following Huffman and Evenson's methodology (1993 and 2001), Stewart (2006) estimated a three-equation SUR (seemingly unrelated regression) model, using indexes of aggregate agricultural, crop, and livestock productivity (TFP) as dependent variables. Explanatory variables tested included measures of domestic prairie agricultural research and development, terms of trade (following Cochrane 1958), farm specialization, farm size, education, extension, off-farm labor, farm/manufacturing wage ratio, and support payments.

Domestic research and development, a "knowledge stock" variable, is calculated as a 20-year stock of federal, provincial, and private sector research and development expenditures. This "knowledge stock" variable leveled off for both crops and livestock in Prairie agriculture since 1990 (Stewart 2006). For both livestock and crops, domestic research and development displayed a positive relationship and was the largest absolute value among the reported coefficients. This finding points to the fundamental role that previous domestic research and development investments have played in productivity growth in both the crop and livestock sectors.

5. SUMMARY AND CONCLUSION

With increasing consolidation and specialization, Canadian primary agriculture has evolved over time to a sector dominated by fewer and larger farms, which account for most agricultural production, although a number of smaller farms continue to operate. As in many developed nations, large farms in Canada account for most of the agricultural production. In terms of farm receipts, red meats, grains and oilseeds (led by wheat and canola, respectively), and dairy are Canada's most important agricultural commodities. However, Canadian farmers have been diversifying their production mix to reach niche markets, increase value added, and spread risk.

Since the early 1960s, the yields of several major crops have increased by approximately 60%. Yield trends for corn, wheat, canola, and peas are remarkably similar, exhibiting consistent absolute growth but declining proportional rates of growth over the period. The assessment of yield changes, however, is complicated by increased cropping intensity (reduced summer fallow), more cropping diversity, and ongoing changes in cropping technology (reduced tillage and low-disturbance seeding systems), particularly in Western Canada. Interesting evidence from crop field trials shows that trial yields for canola and peas have grown more rapidly than for wheat since 1960. This raises the perplexing question of why actual realized yield growth trends have been so similar across these crops.

An assessment of partial productivity measures for the Canadian livestock sector indicates many areas in which production efficiency has improved substantially: higher carcass weight for beef animals, much more production per sow, and major increases in milk production per dairy cow. These "yield" improvements have occurred as Canada's livestock production has become concentrated, in more intensive operations, on many fewer but generally much larger farms.

Based on national time-series data reported by Statistics Canada, labor productivity in crop and animal production in Canada grew rapidly, at 4.7% per year from 1961 to 2005, reflecting, at least in part, the considerable substitution of capital for labor that continued during this period. It is possible to infer from Statistics Canada's national accounts data that TFP growth for crops and livestock, considered together, was considerably slower, ranging from less than 1.0% per year (based on gross output measures) to some 1.4% per year (based on value added measures). More research on productivity estimation and analysis that is directed explicitly to the agricultural sector could clarify these differences and strengthen understanding of agricultural productivity in Canada.

There are major advantages and insights in more detailed assessment of production structure, its evolution, and productivity performance for a major agricultural region such as Western Canada's Prairies over a lengthy time span (Stewart 2006). Productivity growth, exceeding 1.5% per year, has been very important historically in Prairie agriculture, generating nearly two-thirds of output growth. Crop productivity growth outpaced that of livestock, but not in the past 10 or 15 years. The decomposition of estimated productivity growth suggests that technical change has been critical in the crops sector, whereas the roles of technical change and scale impacts have been roughly equal in the livestock sector. R&D expenditures have been a key causal factor underpinning productivity growth in agriculture.

Slower growth in agricultural R&D in Canada seemingly underlies slower productivity growth in the past 10 to 15 years. It is possible that the upswing in livestock productivity, relative to slower growth in crop productivity in the last decade, may be associated, at least in part, with elimination of the Crow

Rate subsidy on grain moving to export position. This change in policy provided more economic incentives for livestock feeding in Western Canada, but more work is needed on this front to fully ascertain the full impact of this policy change. Similarly, more research is needed on whether agriculture in Alberta and western Saskatchewan has suffered from the recent energy/oil boom and adverse "Dutch disease" impacts. A final caveat is that the TFP growth measures reported here are "private" and not "social" or environmentally adjusted productivity measures (Hailu and Veeman 2001). The incorporation of environmental externalities such as nitrate leaching, pesticide damage, and air and water pollution from agricultural production poses difficulties but would provide a better indication of productivity performance from a social perspective.

In summary, overall the study of Canadian crop yields (a partial productivity measure) and, to a lesser degree, the analysis of total factor productivity growth in the crops sector in the Prairie region of Western Canada indicates a slowdown of productivity growth in crop production in the past two decades. Increased funding for agricultural research would help to counter the productivity slowdown in crops and to ensure that future productivity growth in the livestock sector could be based relatively more on technical change and less on scale economies associated with output expansion. Improved productivity performance, led by increased funding for R&D, is critical to the future competitiveness and economic sustainability of Canada's primary agriculture.

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CHAPTER 7

Agricultural Productivity in the United Kingdom

Jenifer Piesse and Colin Thirtle

1. INTRODUCTION

For much of 2008, soaring food commodity prices made headlines in the news. Rising prices are the market's signal that supply is not keeping pace with demand, so the events of 2008 have led to a reappraisal of the world's ability to feed itself. In a recent review (Piesse and Thirtle 2009) of the events of 2008, we showed that world food security is not a foregone conclusion. The long-standing conventional wisdom that science increases supply faster than population and income growth increase demand has to be questioned. With this in mind, we distinguish between three productivity measures, as their implications differ. These are yields, which, with area harvested, determine output; labor productivity, which correlates with incomes; and total factor productivity (TFP), which distinguishes between technical progress, efficiency change, and input intensification. Hence TFP growth has different implications depending on the cause.

2. OUTLINE

To put the chapter in context, the next section gives a very brief account of the main policy changes in the United Kingdom that have affected agricultural

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productivity since the Second World War. Section 4 is historical, covering partial measures, that is, yields and labor productivity. Section 5 explains the current UK TFP methodology, followed by the full TFP results and analysis. The limitation of the national TFP is that it cannot be decomposed by region or crop. Thus, Section 6 presents regional data, but only for the eastern counties of England and only from 1970 to 1997. This is at the crop level and shows the importance of crop switching to increasing TFP. Then, Section 7 covers the international productivity comparisons that are most relevant. These are for the United States and the European Union (EU) countries and for the older EU members and those that acceded in the last few years. Section 8 offers explanations of the productivity changes in the United Kingdom, and the final section summarizes the results and notes the limits of our knowledge in this area.

3. POLICY CHANGES AND LIVESTOCK DISEASES

During the Second World War (WWII), agriculture was subjected to state control, which included compulsory cropping orders, land reclamation, and the eviction of inefficient farmers. Food was rationed and animals were slaughtered because feed was too scarce to keep them. Thus, arable output was maximized, as the main objective was to reduce imports to save shipping space, which was essential to the war effort. By the end of the war the United Kingdom was bankrupt and in debt, so recovery was slow, and state control of agriculture and food rationing was not ended until 1953-54 (Self and Storing 1962). This was followed by a long period typified by cooperation between the state and agricultural organizations, and support was provided by producer subsidies and marketing boards.

This situation persisted until UK membership in the European Community, and new arrangements were phased in beginning in 1973 (Hill 1984). The Common Agricultural Policy (CAP) replaced subsidies with variable levies, which in most cases increased prices for producers as well as consumers. The increased profitability may be expected to have an impact on agricultural investment and productivity. The CAP levels of support were extremely expensive for the taxpayer and led to surpluses that exacerbated the situation because of high storage costs. This led to restrictions such as milk quotas beginning in 1984, which heralded a new era of low profits. Policy moved away from encouraging production and toward environmental stewardship. EU policies such as the set-aside requirement followed in 1992 under the MacSharry reforms and led to the decoupling of output and agricultural support payments.

These policy changes were accompanied by a marked change in agricultural R&D expenditures, which had grown at 7% per annum from the end of the war to the early 1980s but then dropped in real terms because of the Thatcher government's antipathy to the public sector. By the end of the decade, expenditures were fairly steady, but then in the 1990s there was a clear retargeting of agricultural R&D away from productivity-enhancing research and near-market research, which were deemed to be the responsibility of industry, and toward areas of public interest (Thirtle, Palladino, and Piesse 1997). The effects of these changes in policy can be seen in the analysis of agricultural productivity that follows. The Animal Disease Laboratory at Pirbright suffered heavy funding cuts in the 1980s before the appearance of bovine spongiform encephalopathy (BSE), commonly known as mad cow disease, in 1996 and foot-and-mouth disease in 2001, both of which prolonged the United Kingdom's slump in TFP growth.

4. PARTIAL AND TOTAL FACTOR PRODUCTIVITY IN HISTORICAL PERSPECTIVE

The agricultural history of the United Kingdom has attracted considerable attention since the realization that the world's first industrial nation had an agrarian revolution prior to the industrial transformation. From Karl Marx onward, the nature of these two revolutions that ushered in the era of modern economic growth has been hotly disputed. In fact, it is generally agreed that this was the second UK agricultural revolution, the first being much earlier in medieval times.

Historians estimate that the population of England may have tripled between 1100 and 1340, from 1.5 million to 4.5 million, and that such an increase was made possible by agrarian changes that can be claimed to constitute a revolution. Duby (1954) dated the revolution from about 800 to 1100, while White (1962) suggested 700 to 1000. Both placed most emphasis on improvements to the plough, the replacement of oxen by horses, and the switch from a two-course to a three-course rotation system. The two-course rotation reflects Mediterranean practices and means half the land is left fallow each year, while in England there is actually enough rain to sow a spring crop of oats, peas, or beans and get two-thirds of the land under cultivation in any year. Possibly the imperialist Roman invaders imposed the two-field system brought from their homeland, believing that all things Roman were of course superior to the habits of the barbarians.

The dating of the second agrarian revolution varies from 1760 to 1815 in early works covered by Grigg (1982) to 1750 to 1880 in later assessments

(Chambers and Mingay 1966). The advances most discussed include further plough improvements, use of seed drills (associated with agriculturist Jethro Tull), and more hoeing to control weeds. However, the mechanical innovations were not intended to be labor saving, as they were in America. Rather, labor use increased with a view to getting more output. Other key improvements were changes in crop rotations that featured nitrogen-fixing legumes like turnips (wrongly attributed to Viscount Townsend), which also helped feed the increasing number of animals following improved selective breeding (associated with Robert Bakewell). There was also a new development in the large-scale purchase of off-farm inputs, such as field drainage and the construction of new buildings, as well as purchased fertilizer and feed.

The changing rotations and selective breeding were made much easier by the change in land tenure arrangements as the open fields were converted into self-contained farms with fee simple tenancy. This allowed those who wanted to innovate to do so without the need for general agreement. At the same time the ownership changes were causally prior to capital expenditures, as owners could now appropriate the full returns to their investments. Thus, whereas Marx believed technical change was the driving force, modern institutionalists such as North (1990) make a convincing case that all else followed from getting the incentives right.

These stories are entertaining, but the statistical data on changes in output, yields, labor productivity, and TFP leave a lot to be desired. It was not until 1866 that the Board of Agriculture began an annual publication of labor force, land use, and livestock data, adding crop yields in 1885. Thus, there is little evidence on the output and productivity effects of the medieval agrarian revolution. Grigg (1982) reported a 200% increase in the population of England and Wales from 1700 to 1850 and a 264% increase in arable output. He estimated that 62% or almost two-thirds of this came from area expansion (including the reduction in fallow land), rather than yield increases. This is despite data that show that grain (mainly wheat) yields in East Anglia approximately doubled over the period, as the average would have been much lower.

Labor use and productivity is more emotive; Marx and others painted a grim picture of smallholders losing their common land to enclosures and being forced to seek work in the dark Satanic mills of Manchester and other rapidly growing industrial centers. There is now evidence that the agricultural labor force increased until 1850, which marks the turning point in the structural transformation at which point the decline in agricultural employment began. Even so, labor productivity grew as output outstripped labor growth. Grigg (1982) reported that output tripled from 1700 to 1850, while the labor force increased by between 50% and 75%, giving an annual labor productivity growth rate of 0.83% to 1.0%. He also stated that labor productivity grew at 1% per annum from 1800 to 1850, because of output growth, and then grew at the same rate from 1850 to 1900, mostly because of the decline in labor, as industrial employment outstripped population growth. This implies that labor productivity grew at almost 1.0% per annum in the 1700s and then accelerated slightly in the 1800s. There is plenty of disagreement on labor productivity. For instance, Brunt (2003) estimated that labor productivity grew at only 0.29% per annum from 1700 to 1775 and declined at 0.06% per annum from 1775 to 1845.

From 1880 on there are sufficient data to construct estimates per decade, and these are reported in Table 7.1. In the 1880s the decline in ocean freight rates opened the United Kingdom up to competition that had been expected ever since the repeal of the Corn Laws in 1846, which signaled the end of protectionism. First grain imports from Russia and the North American prairies and then meat from the antipodean dominions ended the age of high farming. Labor productivity stuttered and then rose at an increasing rate as the mechanical revolution allowed increasing amounts of labor to enter industrial employment. However, it is not until WWII that growth exceeded 1%, making the earlier estimate seem high.

Data on yields are patchy before 1850, and we rely on Grigg's (1982) best guess that arable yields in England grew at 0.5% per annum from 1700 to 1850. Brunt (2003) was again less optimistic, putting yield growth from 1705 to 1775 at 0.3% per annum and, importantly, arguing that it stayed the same from 1775 to 1845, which must include the key period of the agrarian revolution. The even more contentious issue is the previous century, in which data from Norfolk and Suffolk suggest a 1% per annum growth rate in the first two-thirds of the century, before legumes and clover were added to the rotations. The data again cover the post-revolution period, showing low and erratic growth rates, averaging 0.15% per annum for the periods before WWII. Then, yield growth jumped to new levels entirely (see Table 7.2).

Table 7.1. Output rate of increase per male worker, 1880-1960 (% per annum)

	1880-1890	1890-1900	1900-1910	1910-1920	1920-1930	1930-1940	1940-1950	1950-1960
Increase	0.8	0.25	-0.2	0.7	0.7	2.2	2.4	2.9

Sources: Grigg 1982; Hayami and Ruttan 1971.

Table 7.2. Rate of increase in output per hectare, 1880-1960 (% per annum)

	1880-1890	1890-1900	1900-1910	1910-1920	1920-1930	1930-1940	1940-1950	1950-1960
Increase	0.2	-0.5	0.35	0.2	0.5	1.7	1.4	1.9

Sources: Grigg 1982; Hayami and Ruttan 1971.

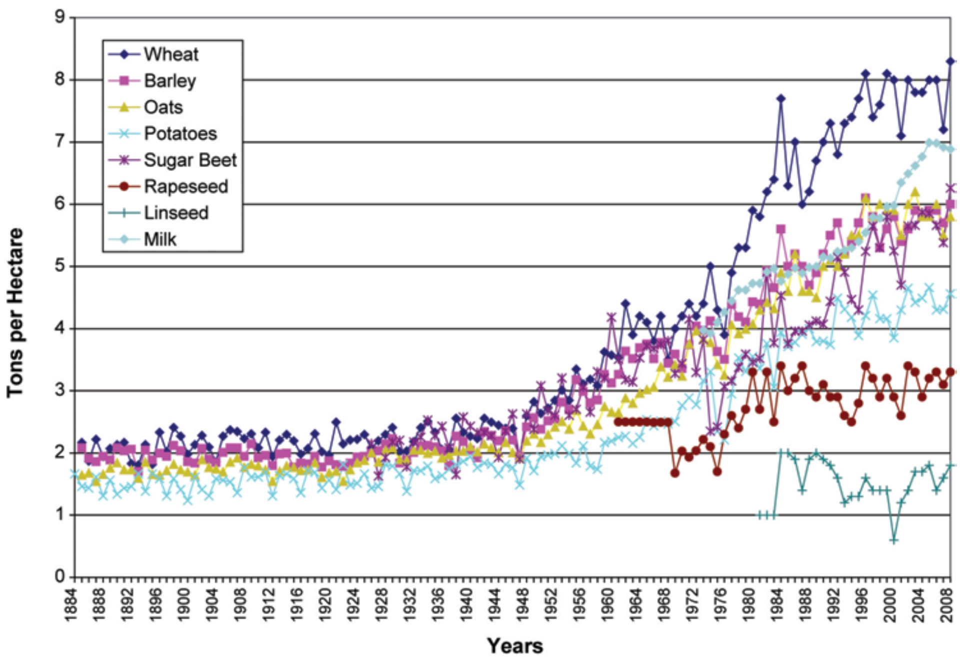

Figure 7.1. Yields of main crops and milk, United Kingdom
Sources: See Data References Appendix.

Yield data are available for the main crops from 1885 onward, and as Figure 7.1 shows, these data confirm the impression given by Table 7.2 that yields of wheat, barley, oats, and potatoes grew very little prior to the end of WWII. The mean growth rate, reported in Table 7.3, is only 0.27% per annum. Only sugar beets, which was then a new crop, had a higher growth rate of 0.79% per annum from 1925 for the period reported.

Thus, the first structural break appears with the application of plant science after WWII, when research-led productivity growth had its golden age. Until the 1990s, the growth rate of the four major crops was about 2% per annum, rather than 0.2%. Sugar fared even better, growing at almost 5% per annum until 1973 and then at almost 2% for the rest of the period. Sugar is a separate crop, grown under the auspices of the British Sugar Corporation (BSC), which has become part

Table 7.3. Annual growth rates of crop yields (% per annum)

Years	Crop	Growth Rate	t Stat	Adj R^2
1885-1945	Wheat	0.24	4.24	0.22
	Barley	0.14	2.78	0.1
	Oats	0.37	8.39	0.54
1948-1996	Wheat	2.31	20.73	0.94
	Barley	1.76	26.4	0.94
	Oats	2.02	34.88	0.96
1996-2008	Wheat	0.12	0.33	0.01
	Barley	0.27	0.89	0.07
	Oats	-0.29	-01.13	0.1
1961-1987	Rapeseed (Canola)	1.25	3.0	0.24
1987-2008	Rapeseed	0.38	1.25	0.03
1985-2008	Linseed	-0.09	-1.21	0.02
1884-1945	Potatoes	0.34	5.26	0.3
1948-1992	Potatoes	1.98	18.29	0.89
1993-2008	Potatoes	0.58	2.1	0.19
1973-2008	Milk	1.53	27.16	0.96
1925-1945	Sugar	0.79	1.61	0.08
1945-1973	Sugar	4.94	5.69	0.57
1976-2008	Sugar	1.91	12.08	0.82

Sources: See Data References Appendix.

of Associated British Foods. Here, R&D was funded by BSC, with a matching levy (mandatory check-off scheme) imposed on farmers. The success of this arrangement, with most of the research being conducted at the Broom's Barn research station of the Biotechnology and Biological Sciences Research Council (BBSRC), which is dedicated to sugar, is reported in Thirtle 1999.

Aside from sugar beets, the other main crops have a second break point in 1996, or 1993 for potatoes. After these dates, the growth rate for potatoes falls to 0.58% and for the cereals it returns to about 0.2%, just as it was before the advent of publicly funded research after WWII. The reasons for this reversal have been investigated previously by Thirtle et al. (2004a) and will be considered in Section 10. With the benefit of hindsight and more data, it can be said that UK R&D expenditures declined from 1982 and were targeted away from productivity enhancement, so it seems likely that after 14 years this policy change has had a serious impact. However, there are other explanations, including the possibility that ongoing, rapid productivity growth is a passing phase and not a foregone assumption. The recent scientific revolution has lasted no longer than its predecessors in the UK case, but is this caused by the funding cuts, or is there a return to the historical growth path as the scientific revolution enters its late phase?

The final issue is total factor productivity (TFP), or appropriately weighted aggregate output per unit of appropriately weighted aggregate inputs. Brunt (2003) estimated TFP growth despite the lack of data. His estimates show a rate of TFP growth of 0.17% for the period 1705 to 1775 and -0.01% (that is zero, statistically speaking) from 1775 to 1845. Other estimates of TFP growth for the second period range from 0.24% per annum to 0.67%. We noted earlier one reason why they are fairly low, namely, that there was an increase in non-farm inputs and some level of capital accumulation, which Grigg (1982) showed more than tripled from the 1760s to the 1850s.

5. RECENT PARTIAL AND TOTAL FACTOR PRODUCTIVITY

The crop-specific data reported in the previous section straddles the ancient past and recent times, as it begins in 1884 and continues to 2008. From 1953 onward it is possible to report consistent series on outputs, inputs, yields (measured as value of output per hectare), output per worker, and TFP using decent annual data and established methods (Tornqvist-Theil index and Fisher's ideal index). This is an update of a report by Thirtle et al. (2004b), which in turn was extracted from a report (Thirtle et al. 2003) to the Department of the Environment, Food and Rural Affairs (DEFRA). The older material was first published in an article by Thirtle and Bottomley (1992).

From 2000 to 2003 the Ministry of Agriculture, Fisheries and Food (MAFF, replaced in 2001 by DEFRA) funded a project to upgrade the statistics used for productivity measurement. Details are in the report by Thirtle et al. (2004b) but the methodology is briefly noted in this chapter. The result is that DEFRA now uses methods almost identical to those of the U.S. Department of Agriculture (USDA), as we advised DEFRA in conjunction with Eldon Ball. The only major difference is that the USDA uses Fisher's ideal index rather than the Tornqvist-Theil index, because it better fit the USDA's system. This does not affect results much in our experience, so our TFP is our own Tornqvist from 1953 to 2000, updated to 2008 using the DEFRA index.

We begin by reporting the output, input, TFP, land, and labor productivity indexes and then look at outputs and inputs at various levels of aggregation. Table 7.4

Table 7.4. Output, input, TFP, labor, and land productivity indexes, 1953-2008

Years	Output Index	Input Index	TFP	Labor Productivity	Land Productivity
1953	100	100	100	100	100
1954	105.7	105.1	100.5	107.3	105.9
1955	103.7	103.2	100.5	110.8	103.9
1956	110.7	104.6	105.9	122.4	111.0
1957	112.2	107	104.9	125.5	112.7
1958	113	106	106.6	129.1	113.6
1959	118.3	107.1	110.4	139.3	119.5
1960	122.5	106.8	114.7	150.1	123.8
1961	127	108.6	117	162.4	129.2
1962	133.8	109.6	122	173.9	136.1
1963	135.3	109.6	123.5	181.3	137.7
1964	131.3	105.3	124.7	186.1	133.4
1965	133.1	104	128	194.7	135.3
1966	133.5	101.3	131.7	207.5	135.6
1967	137.8	99.9	137.9	225.4	140.2
1968	138.9	100.2	138.5	228.6	142.2
1969	143.7	103.1	139.4	244.6	145.8
1970	148.7	105.8	140.6	268.5	154.6
1971	152.7	105.5	144.8	260.1	158.8
1972	153.9	106	145.1	268.4	160.7
1973	155.7	105.2	148.1	266.7	163.0
1974	160	106	151	279.4	167.3
1975	154.4	109.5	141.1	274.5	161.7
1976	149.4	109.6	136.3	270.9	156.4
1977	159.3	108.5	146.8	296.2	168.1
1978	166.6	108.8	153.1	312	175.7
1979	169.1	111.7	151.3	323.4	178.5
1980	173.6	110.3	157.4	340.9	182.1
1981	173.4	107.6	161.2	350.1	183.3
1982	182.3	110.3	165.3	374.8	192.9
1983	181.8	113.4	160.3	377.6	192.9
1984	195.7	112.7	173.6	420.8	207.8
1985	190.6	113.5	168	415.5	202.6
1986	191.4	113.8	168.2	437.4	203.7
1987	190.3	113.7	167.5	441.7	203.2
1988	189.3	113.7	166.5	453.4	202.6
1989	191.6	111.9	171.2	476.9	205.3
1990	190.9	110.8	172.2	486.1	205.0
1991	194.1	111.2	174.5	510.8	208.8
1992	194.7	109.5	177.8	532	210.9
1993	189.2	108.2	174.8	533.1	210.7
1994	191.1	108.4	176.3	556.5	213.4
1995	192.6	111	173.6	578.2	215.4
1996	190.8	111.3	171.4	584.3	211.8

Table 7.4. Continued

Years	Output Index	Input Index	TFP	Labor Productivity	Land Productivity
1997	188.4	109.6	171.9	587.4	208.2
1998	188.6	108.6	173.6	601.4	205.1
1999	189.9	107.2	177.2	627.9	209.6
2000	187.2	105.5	177.5	679	209.7
2001	179.7	104.0	172.9	609.1	198.6
2002	186.6	101.1	184.8	900.4	206.8
2003	184.8	98.5	187.6	911.9	205.4
2004	186.1	99.5	187.3	894.2	207.1
2005	188.7	97.4	193.8	1040.2	209.2
2006	182.7	94.8	192.6	1048.4	199.5
2007	180.5	94.7	190.6	985.2	198.0
2008	188.9	96.4	196.0	1108.8	207.1

Sources: See Data References Appendix.

begins with the output index, which starts from the conventional arbitrary value of 100 and rises to 188.9, so output increased by 89% over the full period. Inputs, in the second column, actually fell by 2.6%, so productivity has increased, as the third column shows, to 196, which is a gain of 96%. Output per unit of land, or yields, more than doubled, and labor productivity increased enormously, to 1108, or a little over 11 times its initial value. The huge difference between TFP and yields relative to labor productivity results from the substitution of other inputs for labor, which is a leading feature of developed country agricultural progress.

Figure 7.2 plots all the indexes except labor productivity (which has a larger scale) and makes interpretation much easier. The decline in output and TFP caused by the droughts of 1975 and 1976 can be seen clearly in the yield and output series, but apart from this period of unusually poor rainfall, output, yield, and TFP rise at a fairly steady rate until 1984. At that point, output and yield growth ceased and the TFP grows much more slowly, powered by the slight decline in inputs. Output does not recover until the last food price crisis year of 2008, and even then it is still below the average levels for the 1980s and 1990s. Yields do not recover at all and in 2008 were still as low as in 1984. However, comparison with Figure 7.1 and Table 7.3, for individual crop yields, suggests that 1984 was in fact a particularly good year and that the yield decline may be better dated from the mid-1990s. Until then growth was slower but positive, whereas after that date it appears to actually be negative. For inputs, the structural break seems to be at 1996, when slow growth turned to quite rapid decline.

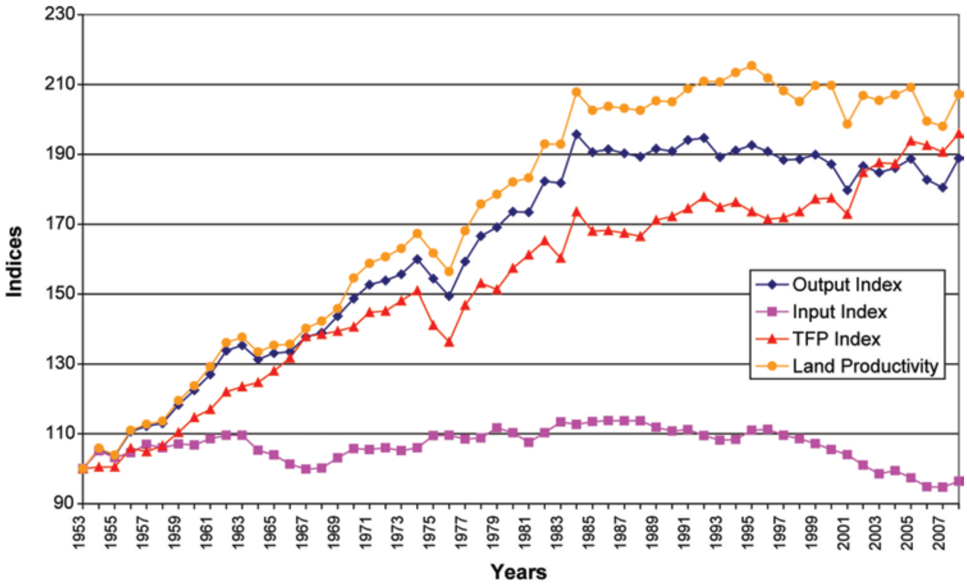

Figure 7.2. Output, input, and TFP indexes
Sources: See Data References Appendix.

Having identified these turning points in the series,[1] we use this information to construct the annual average growth rates in Table 7.5. Over the full period, output grew at 1.10% per annum, while inputs were unchanged, with a negative growth rate of 0.04% per annum, which is statistically insignificant (note the lack of fit too: the adjusted R^2 is 0.004). Since TFP is the ratio of these series in logarithms, it grows at 1.14% per annum, which is a lower growth rate than earlier studies reported. Thirtle and Bottomley (1992) estimated TFP growth at 1.77% per annum up to 1990, and Amadi (2000) and Barnes (2002) both covered the period to 1995, with estimates of 1.81% and 1.93%, respectively.

The reason for lower growth rates of output and yields in this study is the poor recent performance. The first column of Table 7.5 shows that since 1984 output has declined at 0.02% per annum, and the fourth column shows that yields declined at 0.03% per annum over the same period. Note too that output follows yields very closely, which is because the area harvested varies very little. Indeed, the adjusted R^2 is 0.995, so the variance in output is almost entirely ex-

[1]This does appear to be a clear break in both the output and TFP series. However, statistical tests, based on the latest techniques in time-series econometrics, fail to determine that there is a break. This suggests that the length of series that is required for such tests makes them of little value in this type of investigation.

Table 7.5. Annual average growth rates (% by period)

Years	Output Index	Input Index	TFP Index	Output per Unit of Land	Output per Unit of Labor
1953-2008					
Growth rate	1.1%	-0.04%	1.14%	1.31%	3.96%
t Statistic	15.54	-0.88	24.31	18.10	58.17
Adjusted R^2	0.81	0.004	0.91	0.85	0.98
1953-1984					
Growth rate	1.87%		1.67%	2.08%	
t Statistic	29.65		22.23	32.78	
Adjusted R^2	0.96		0.94	0.97	
1953-1996					
Growth rate		0.19%			
t Statistic		6.06			
Adjusted R^2		0.45			
1953-2000					
Growth rate					3.86%
t Statistic					51.53
Adjusted R^2					0.98
1984-2008					
Growth rate	-0.02%			-0.03%	
t Statistic	-4.88			-0.52	
Adjusted R^2	0.49			0.01	
1984-1996					
Growth rate			0.30%		
t Statistic			2.30		
Adjusted R^2			0.26		
1996-2008					
Growth rate		-1.42%	1.21%		
t Statistic		-15.13	9.53		
Adjusted R^2		0.95	0.88		
2000-2008					
Growth rate					6.40%
t Statistic					4.59
Adjusted R^2					0.71

Sources: See Data References Appendix.

plained by yield changes. However, the lower TFP growth rate is more complicated. Column three of Table 7.5 shows that TFP growth was slower than the older estimates even over the period from 1953 to 1984, when it was growing fastest, at 1.67% per annum. Then the rate fell to only 0.3% per annum until 1996. It has recovered to 1.21% since 1996. The decline in TFP growth in the early period reflects the complete overhaul of the UK productivity data reported in Thirtle et al. (2004b), which gave a growth rate from 1953 to 2000 of 1.26% per annum. The increased level of detail in the new DEFRA data picks up more quality change, and when this is properly measured, less is attributed to TFP growth.

Figure 7.2 also shows that the recent recovery in TFP is not driven by output growth but by falling inputs. The second column of Table 7.5 reports that inputs grew at 0.19% per annum until 1996, and since then they have fallen at 1.42% per annum, which is a rapid decline in TFP accounting terms. The last column of Table 7.5 is also relevant here, as it reports labor productivity growth, and it is the rapid fall in labor inputs that drives TFP growth in the developed counties. Labor productivity is plotted in Figure 7.3, along with the yield index, to show how much faster it has grown. This was at 3.86% per annum until 2000, but since then it has jumped to 6.4% per annum. Labor productivity can be expected to rise when machinery and equipment are increasingly being substituted for labor, but this has not been the case. Indeed, Fuglie (2008) identified a decline in agricultural investment as a key driver of productivity growth in the recent past. Since a large part of investment is machinery, it seems likely that this has been decreasing, and we investigate this next.

The changes in the component parts of the output and input indexes are shown in the columns on the left side of Table 7.6. We begin by reporting average shares

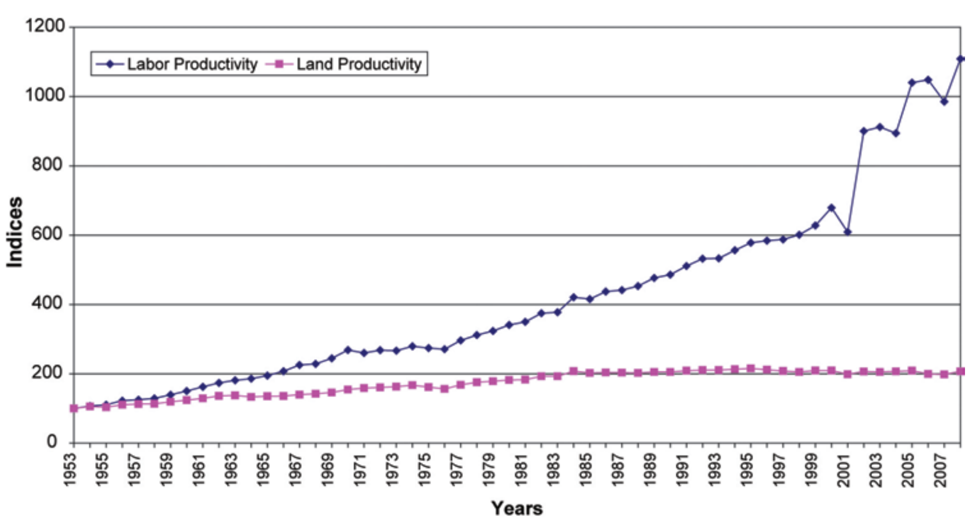

Figure 7.3. Land and labor productivity
Sources: See Data References Appendix.

Table 7.6. Shares in revenue or costs and annual mean growth rates

	Shares in Revenue or Cost (%)				Annual Average Growth Rates (%)		
	1953-2000	1953-1984	1984-2000	2008	1953-2008	1953-1984	1984-2008
Outputs							
Crop outputs	22	20	26	29	1.68	1.70	0.04[b]
Horticulture & fruit	11	10	11	13	0.12	0.55	-0.68
Livestock	38	38	39	36	1.16	1.83[a]	0.63
Livestock products	29	32	24	22	0.43	1.67	-0.53
Inputs					**1953-2008**	**1953-1996**	**1996-2008**
Seeds	2	2	2	4.5	0.84	1.00	-0.60
Fertilizers	7	7	7	11.0	1.13	2.20	-5.90
Pesticides	2	1	4	4.7	2.85	3.37	-0.69
Feed	23	25	20	28.3	1.00	1.24	0.85
Miscellaneous	6	6	7	9.4			
Machinery	20	19	20	9.0	-0.37	-0.10	-1.39
Buildings	9	7	14	5.1	2.30	3.28	-0.57
Labor	22	26	14	18.2	-2.10	-2.04	-3.21
Land	4	3	6	9.7	-0.13	-0.19	0.22

Sources: See Data References Appendix.
[a]For livestock output the sub-periods are 1953-1995 and 1995-2008.
[b]Not significantly different from zero.

in total revenue, from 1953 to 2000, so that the relative importance of each output can be judged. The shares show that animal products have declined in importance while crops have become more important, but even so this has only reduced the share of animals and animal products from 67% of total revenue to 63%. Updating to 2008 shows that by the final year, animals and animal products had declined further, to only 58% of total revenue, but we will see next that this is the result of an unusually high level of cereal output in response to the high prices of 2008.

The columns on the right side of Table 7.6 report that over the full period, from 1953 to 2008, crop output grew at 1.68% per annum, livestock at 1.16%, and livestock products at 0.43%, while horticulture and fruit output was virtually stagnant, growing at only 0.12% per annum. UK producers have lost market share to imports, as these items have increased their share in consumer expenditures. Even in the early period, prior to 1984, there was little growth in horticulture and fruit, while the other three outputs grew at a minimum of

1.67%, as can be seen in Figure 7.4. After 1984, only livestock output grew, with crops stagnant, livestock products falling at 0.5% per annum, and horticulture and fruit output falling at 0.68% per year. This sector has experienced the most rapid and severe withdrawal of public R&D and the biggest gains in exports. The intermediate inputs are reported next in Table 7.6 and plotted in Figure 7.5. The figure shows that the two rapidly growing inputs were fertilizer and pesticides. Growth of pesticides overtakes that of fertilizer in the early 1980s, but by the early 1990s growth has peaked for both. The feed index includes other animal inputs, such as veterinary expenses. Table 7.6 shows that feed inputs began as a big share and retained that importance despite slow growth, while fertilizer and pesticides are relatively unimportant. The rise in the shares of the intermediate inputs in 2008 is mostly due to the huge fall in the capital items, which we cover next.

The structural breaks in the input series occur around 1996, which is when the aggregate input index turned down, so for simplicity this is the date used in Table 7.6. The outcome is not affected, since it is clear that growth was faster before 1996 and since then only feed continued to grow, while fertilizer declined rapidly, at over 5% per annum. This decline is exacerbated by the high prices in the final year, but this is a minor point.

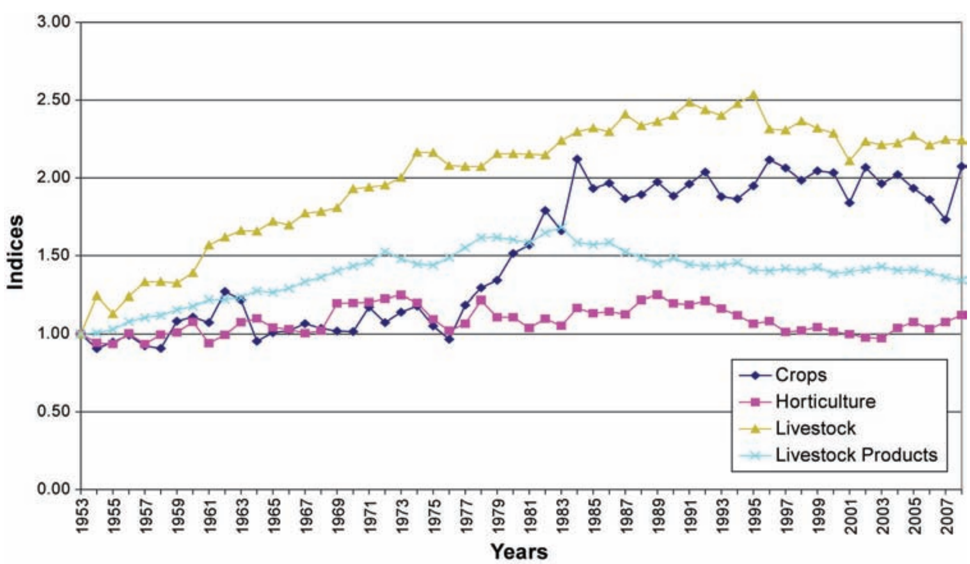

Figure 7.4. Output indexes
Sources: See Data References Appendix.

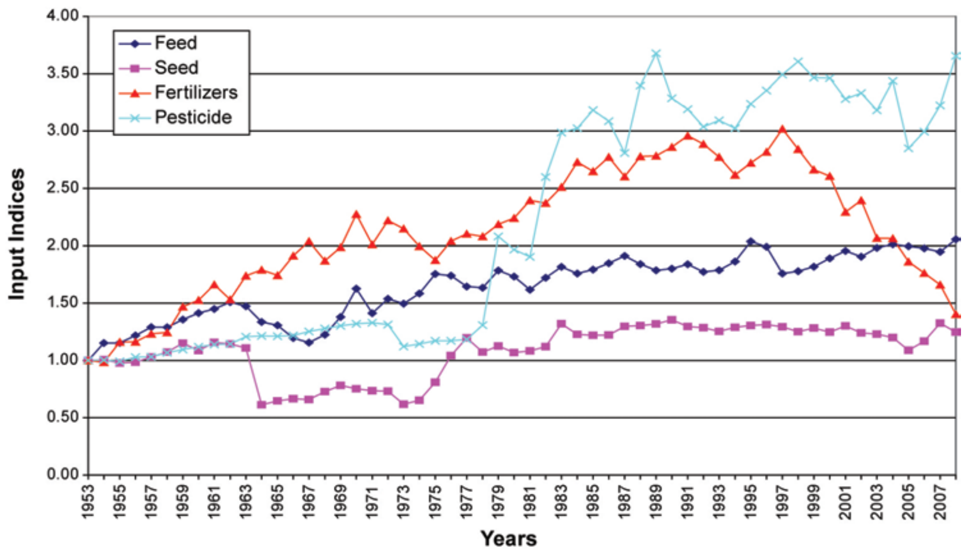

Figure 7.5. Intermediate input indexes
Sources: See Data References Appendix.

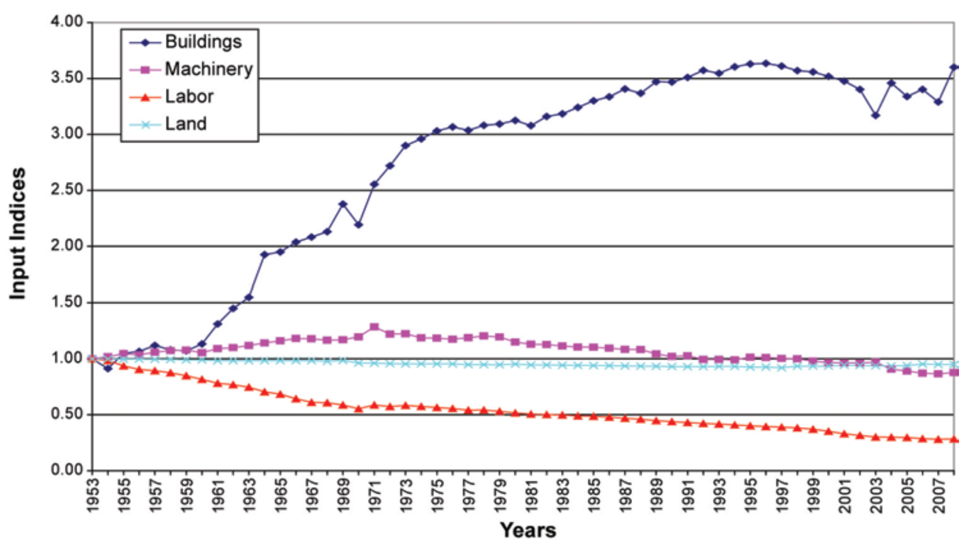

Figure 7.6. Land, labor, and capital indexes
Sources: See Data References Appendix.

Finally, Figure 7.6 plots the inputs of land and labor and the capital inputs. It clearly shows the rapid growth of buildings and land improvements, in contrast with the rapid reduction in labor, which typifies developed country agriculture. Thus, in Table 7.6, the share of buildings and land improvements in total costs doubles over the two periods, while that of labor is practically halved. Machinery maintains its share but grows very little, while land's share doubles by 2000.

Table 7.6 reports that inputs for buildings grew at 3.28% in the early period while labor fell at over 2% per annum. Land is almost constant throughout and machinery declines slightly. A startling aspect of these data are the results from 1996 to 2008, which show that labor's rate of decline has risen to over 3% per annum. It is difficult to conclude how this is being achieved, since the machinery input is itself declining at 1.39% per annum and buildings and land improvements at 0.57% a year. Could it be that the influx of labor from the new EU member states has not been fully recorded?[2] Thus, by 2008, the shares of the capital investment items are incredibly low by historical standards. There appears to have been a dramatic decrease in investment, which also shows in the capital assets section of DEFRA's (2008) accounts.

6. CROP-LEVEL TFP FOR SUGAR AND THE EASTERN UK COUNTIES

The previous section is a traditional analysis of aggregate TFP growth at the national level, which serves as a summary, but if the objective is to cast light on competitiveness, it leaves many questions unanswered. The Tornqvist-Theil index measures the average output, input, and TFP at any point in time but takes no account of dispersion or variance.[3] But there will be variance, between crops and other enterprises, among regions, and between more efficient and less efficient farms. Thus, many recent U.S. productivity studies are at the state level, and Conradie, Piesse, and Thirtle (2008) report TFPs for the Western Cape Province of South Africa at the magisterial district level. Also, nobody trades aggregate agricultural output. A country will tend to export those products in which

[2]Refer back to the erratic increases in labor productivity referred to in Figure 7.3 and discussed in the text, which raised the issue of accuracy of the data.

[3]In this it is inferior to the Malmquist index, which separates technical change (the movement of the best-practice frontier) and efficiency change (the distance of observations from the best-practice frontier). This is important, as lack of movement of the frontier suggests that R&D is having no impact, whereas an increasing number of farms being left behind the frontier indicates that extension is not working well.

it has the most comparative advantage, and import, or at least not export, those in which it is not competitive. Also, the more efficient farms will be in the best position to export, perhaps even to other jurisdictions where the farms are less efficient. Thus, we now show that these variances matter and try to take them into account.

The United Kingdom does not have county-level data, and crop-specific TFPs normally cannot be constructed, as the allocation of some inputs (such as labor) among crops is usually not known. However, there are some exceptions, which serve to demonstrate the importance of variation across crops. First, we have data for sugar beets from Associated British Foods, from 1953 to 1992. The data cannot be feasibly extended to the present, but in Figure 7.7 we demonstrate how different crops can be. The figure shows the difference between the aggregate UK agricultural TFP, which grew at 1.88% per annum, and the sugar beet TFP, which grew at 3.46% per annum (Thirtle 1999).

There are also crop-specific data for sugar, potatoes, oilseed, rape (canola), wheat, and barley for the eastern counties of England, which cover most of the best arable land in the United Kingdom (Murphy 1998 and previous). These data are for 1970-97 only, as collection of suitable data was discontinued. Over this

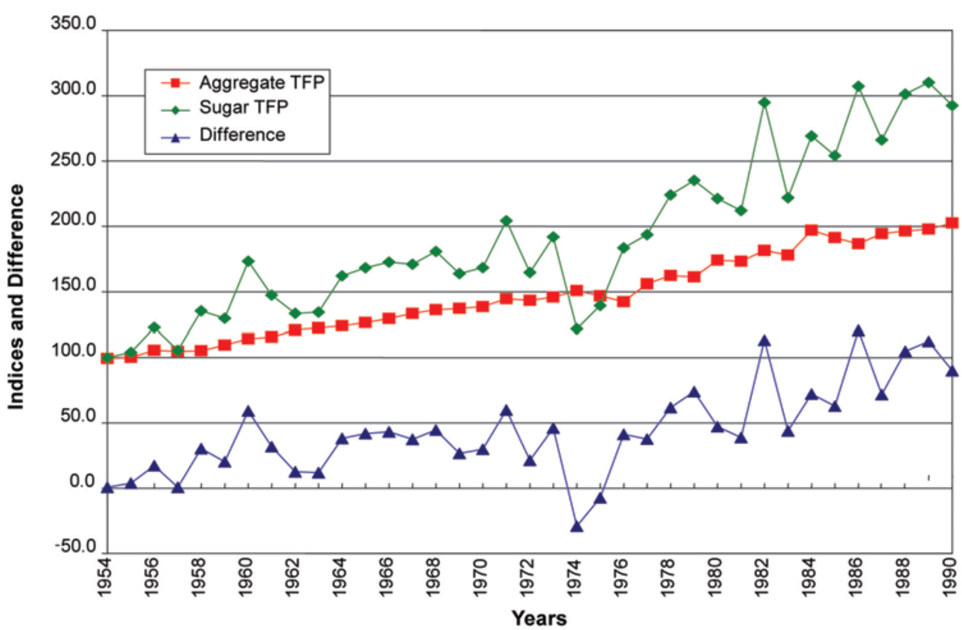

Figure 7.7. Difference between UK aggregate and sugar TFP
Sources: See Data References Appendix.

period, the eastern region accounted for an average of 56% of UK sugar production; 30% of winter wheat output; 26% of oilseed, rape, and potatoes; and 21% of spring barley. Thus, the TFP of these crops, which is a value-weighted aggregate of these indexes, is a reasonable sample of UK crop production. This can be compared to the UK aggregate TFP to see how productivity in crops has differed from that in horticulture and animal production. The more novel aspect of the study is that the sources of aggregate crop TFP can be decomposed into the innate productivity growth of the five crops and the effect of switching from crops with low TFP growth to those that have grown faster.

Figure 7.8 shows that after a poor start, the eastern region had far better TFP growth, at 2.87%, than the UK growth in aggregate, which was only 1.5% per annum. Unfortunately there is no way of comparing the starting levels, which were both set at 100, and this can also be crucial for comparison purposes. The eastern counties aggregate also conceals the very different growth rates across the crops. Oilseed rape grew at 5.77% per annum (but from a low base), sugar at 3.39%, wheat at 2.49%, barley at 1.89%, and potatoes at 1.19% (but from a high base). These comparisons are sufficient to expose the weakness of national aggregate TFPs for investigating relative competitiveness.

TFP growth results from the productivity growth of individual crops and from shifting from crops with low TFP growth to those with higher TFP growth rates. Baily, Bartlesman, and Haltiwanger (1996), and Baldwin (1996),

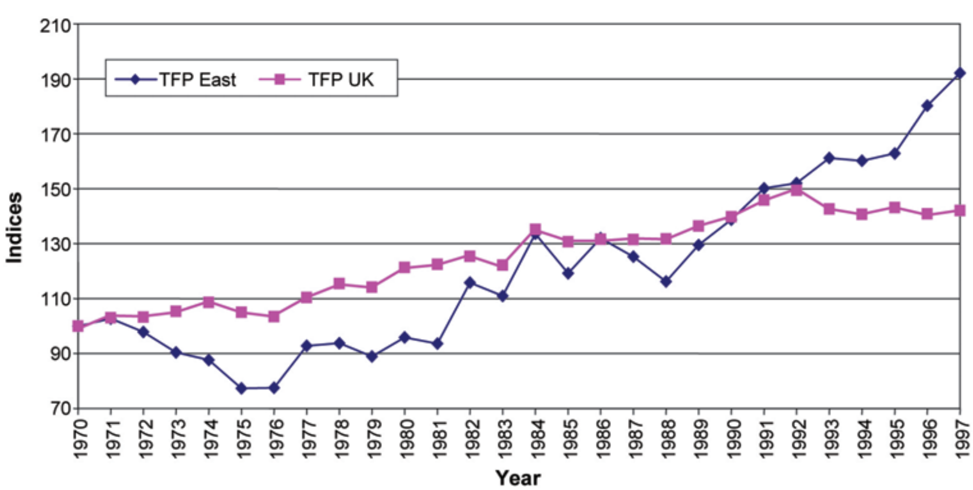

Figure 7.8. Eastern region and UK TFP indexes
Sources: See Data References Appendix.

use plant-level data for the industrial sector to analyze the effect that composition changes have on the translation from plant-level to aggregate productivity data. They show that growth in aggregate TFP can be the result of changes in output share among plants rather than within-plant increases in TFP.

Amadi, Piesse, and Thirtle (2004), following Baily, Bartlesman, and Haltiwanger (1996), calculate the contribution that each crop makes to the proportional annual change in the eastern region TFP, reflecting changes in the productivity of individual crops and the land area weighting, as shown in equation (1):

$$\frac{\Delta TFP_{Et}}{TFP_{Et-1}} = \frac{\sum_{i=1}^{5} \Phi_{t-1,i} \Delta TFP_{t,i}}{TFP_{Et-1}} + \frac{\sum_{i=1}^{5} \Delta\Phi_{t,i} (TFP_{t-1,i} - TFP_{Et-1})}{TFP_{Et-i}} + \frac{\sum_{i=1}^{5} \Delta\Phi_{t,i} \Delta TFP_{Et,i}}{TFP_i} \tag{1}$$

where $\Phi_i = \frac{A_i}{\sum A_i}$ is the area share of the crop. Thus, regional TFP change is decomposed into three terms. The first term indicates how much of the productivity change reflects increases within individual crops and is the change in the TFP of crop i, relative to the regional TFP, with the area share held constant. The second and third terms, in which the area shares change, pick up the changes in productivity due to changes in crop mix. The second term is the product of the change in the area share and the difference between the crop TFP and the regional TFP, relative to the regional TFP value. This can be positive or negative depending on whether the average productivity crops are increasing or decreasing their area shares. The third term is the second crop mix effect, called the cross term by Baily et al. (1996), which is the product of the change in area and the change in the regional TFP, relative to the TFP for crop i. It is positive or negative depending on whether the crops that have positive productivity growth have increasing or decreasing area shares. Thus, each crop contributes not only through its own change in productivity but also because its area share is changing.

The contributions of each crop to overall productivity growth in the eastern region are reported in Table 7.7, where the first term in (1) corresponds to the productivity column. The second term is the input share column, and the cross-effects column corresponds to the third term in (1). The most interesting result, because it has not been previously measured, is shown in the last row, which attributes 77% of growth to the direct, within-crop TFP changes and 23% to crop switching. The input share effects exactly cancel out, leaving the cross term to capture this crop mix effect. The last column shows that wheat made the

Table 7.7. Direct and crop mix contributions of the crops to regional TFP growth, 1970-1995

Crop	Productivity	Input Share	Cross Term	Total	Total %
Sugar	17.92	-0.01	-1.73	16.17	17.55
Potatoes	0.51	-0.01	-0.08	0.42	0.46
Oil seed rape	0.46	0.10	33.94	34.50	37.45
Wheat	25.32	0.20	11.30	36.82	39.96
Barley	27.09	-0.28	-22.60	4.21	4.57
Total	71.31	0.00	20.83	92.13	100.00
Total %	77.39	0.00	22.61	100.00	

Sources: See Data References Appendix.

largest total contribution to the regional TFP, because of its dominance in the region, but oilseed rape, with less than 10% of the acreage, contributes almost as much, followed by sugar beets, while barley adds less than 5%, and potatoes approximately zero. The rest of the table shows the crop-level contributions, so the first row shows that sugar's contribution is entirely due to the direct effect of its rapid TFP growth. The area effect is small and negative, which is not surprising, as yields increased and the crop is subject to quantity quotas. The small contribution of potatoes is also composed of a positive, direct TFP effect and a small negative area effect, which is for the same reasons, as quotas were in force much of the time.

For oilseed rape, the minute area in 1970 results in a very small attribution to the direct effect of TFP change, with the large contribution being recorded under the crop mix effect, as the crop grew in importance to cover almost 10% of the area. For wheat, over two-thirds of the contribution is attributed to the direct TFP growth effect because of the large starting area, but as the area expanded, there is also a crop-switching contribution. Barley shows that the decomposition has to be carefully interpreted. Because of the large area share in 1970 and reasonable TFP growth, barley is recorded as making the largest direct contribution to TFP, which is somewhat counterintuitive, but the effect of the area decline is almost as large, leaving a very small total contribution.

7. INTERNATIONAL COMPARISONS OF PRODUCTIVITY

International productivity comparisons that include the United Kingdom and the United States resulted from a USDA project and began with an analysis by Thirtle et al. (1995). The analysis compared the agricultural TFPs of the 10 countries that then comprised the European Community with the TFP of the

United States from 1973 to 1989. At the beginning of the period, with the average of the 10 EC counties set at 100, the range was from 141 for the Netherlands and 135 for Belgium down to 86 for Greece and 81 for Italy. The United States was placed third in this ranking, with a TFP of 124, and the United Kingdom was fifth, with 110. By the end of the period, the Netherlands still led, followed by the United States, and the United Kingdom had fallen to sixth in the spatial ranking. This was because the UK TFP had grown at only 1.7% per annum, as compared with the EC-10 average of 2.1% per annum, which was also the U.S. growth rate. The TFP changes were explained by public R&D expenditures, private patents, extension expenditures, education, spillovers of public R&D among national jurisdictions, and the weather. The main finding was that the average spillover effects were bigger than the average of the direct effects of national agricultural research systems within the countries of origin.

Schimmelpfennig and Thirtle (1999) updated this work to 1993 and with the extra years of data found that the United States was the leading country in TFP by 1993, as illustrated in Figure 7.9. Advances in the measurement of convergence showed that the United States and the leading northern European countries were converging in TFP to a high-level growth club, while the southern European countries were falling behind and themselves converging on a low-growth equilibrium.

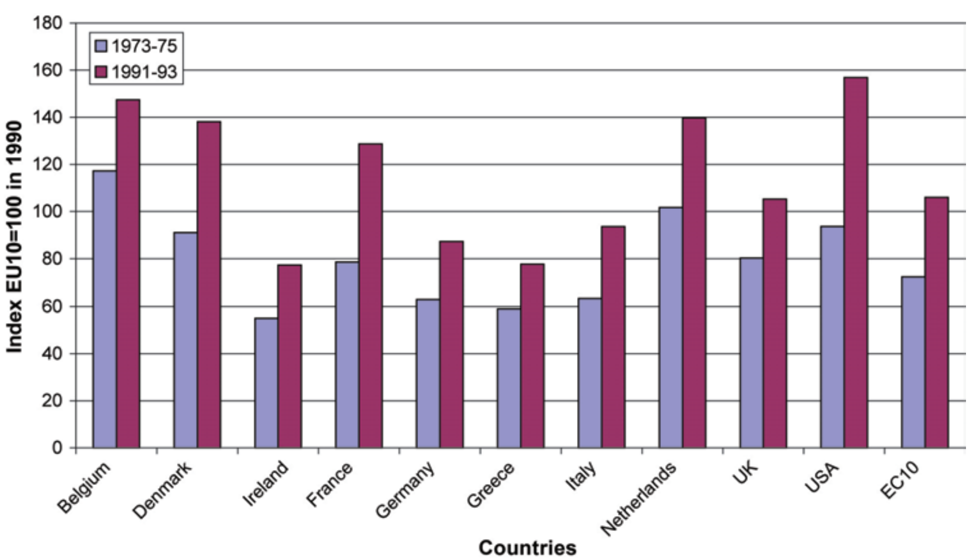

Figure 7.9. Comparing TFP in the United States and the European Community 10
Sources: See Data References Appendix.

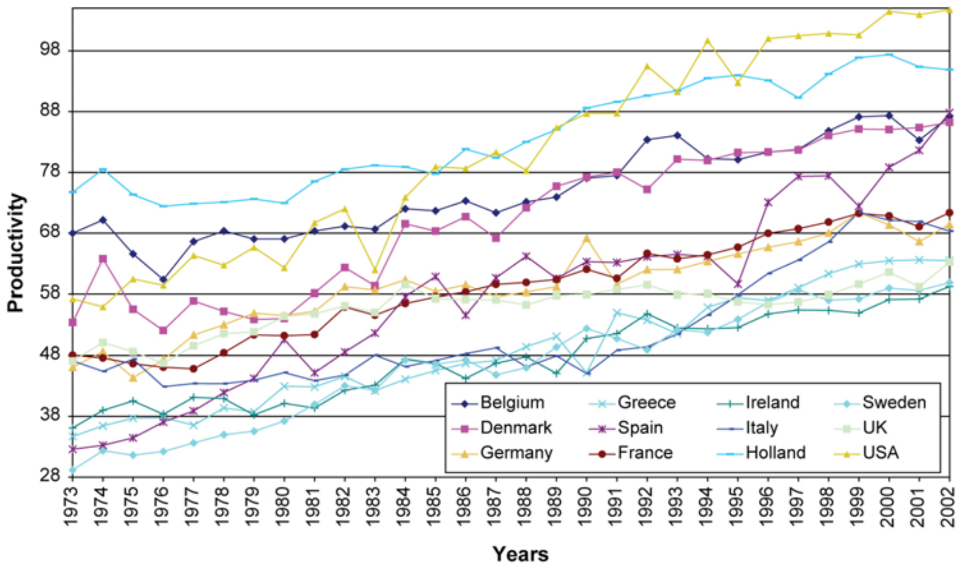

Figure 7.10. TFPs for the EU countries, 1973-2002
Sources: See Data References Appendix.

The most recent update is from Eldon Ball of the USDA and is associated with the competitiveness study of Ball, Butalt, and Mendosa (2004). Figure 7.10, which was constructed from Ball's data, shows that when the TFP comparison is updated to 2002, the United States retains its lead while the United Kingdom has declined to the same level as Sweden, Ireland, and Greece. The lengthy period of stagnation in the United Kingdom is quite clear in Figure 7.10.

A report to DEFRA on the impact on UK agriculture of increasing agricultural productivity in EU acceding countries (Thirtle et al. 2004b) included farm-level data. These data were included because the aggregate results for the study showed that even the most advanced new member states were on average not competitive with the United Kingdom. However, on the basis of the farm-level data, we argued that the top end of the distribution in the new member states would be more efficient than the bottom end of the distribution of UK farms, as shown in Figure 7.11. Foreign-owned, large-scale, advanced technology enterprises in countries like Poland and Hungary had very little in common with those countries' average farms and were almost certainly far more efficient than the tail end of small UK farms, which were struggling. This should be kept in mind when reviewing the work on international comparisons.

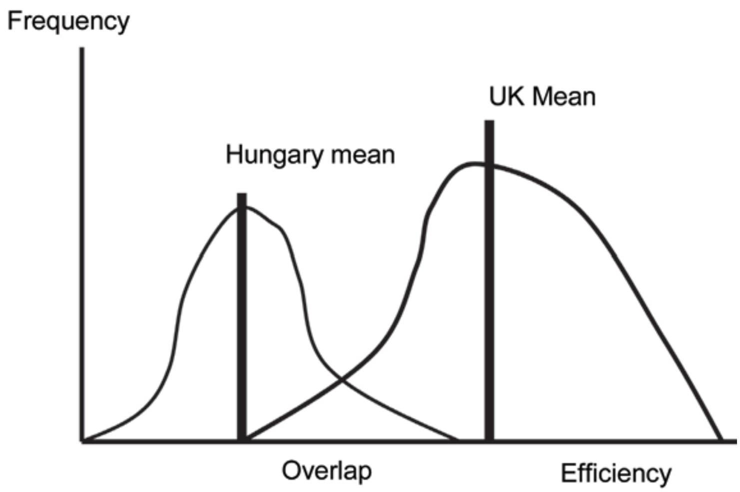

Figure 7.11. Distribution of UK and Hungarian farms

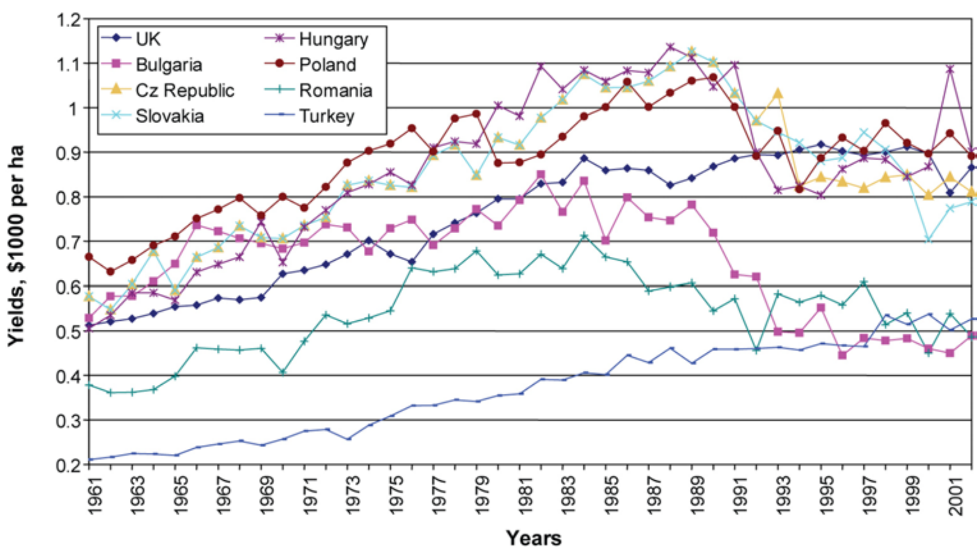

Figure 7.12. Yields, United Kingdom and potential European Union entrants
Sources: See Data References Appendix.

The national aggregate comparisons in the DEFRA report by Thirtle et al. (2004a) used Food and Agriculture Organization (FAO 2005) data to compare aggregate yield in value terms, labor productivity, and TFP. Yields for the United Kingdom and the new member states are in Figure 7.12, which shows that the UK yields were actually considerably lower than those for Poland, Hungary, and the former Czechoslovakia, until these countries suffered setbacks during the transition in the early 1990s. By 2002, yields in the United Kingdom, Poland, Hungary, the Czech Republic and Slovakia were all grouped at around \$800-\$900 per hectare, while Bulgaria, Romania, and Turkey were only at around \$500 per hectare. It is apparent that aggregate yield values generally declined in the 1990s, with Turkey the only exception.

Yields are of great interest to agricultural scientists, but as Hayami and Ruttan's (1985) comparisons of Japan and the United States showed, maximizing yield is of major interest only to countries where land is scarce. The majority of productivity growth in the advanced countries comes from shedding labor. This is reflected in Figure 7.13, which shows the value of annual output per agricultural worker for the full sample of incumbent, new, and potential EU states, in \$1,000 U.S. purchasing power parity, 1990 base. The leading country in this dimension is Belgium/Luxembourg, which by 2002 had output per worker of

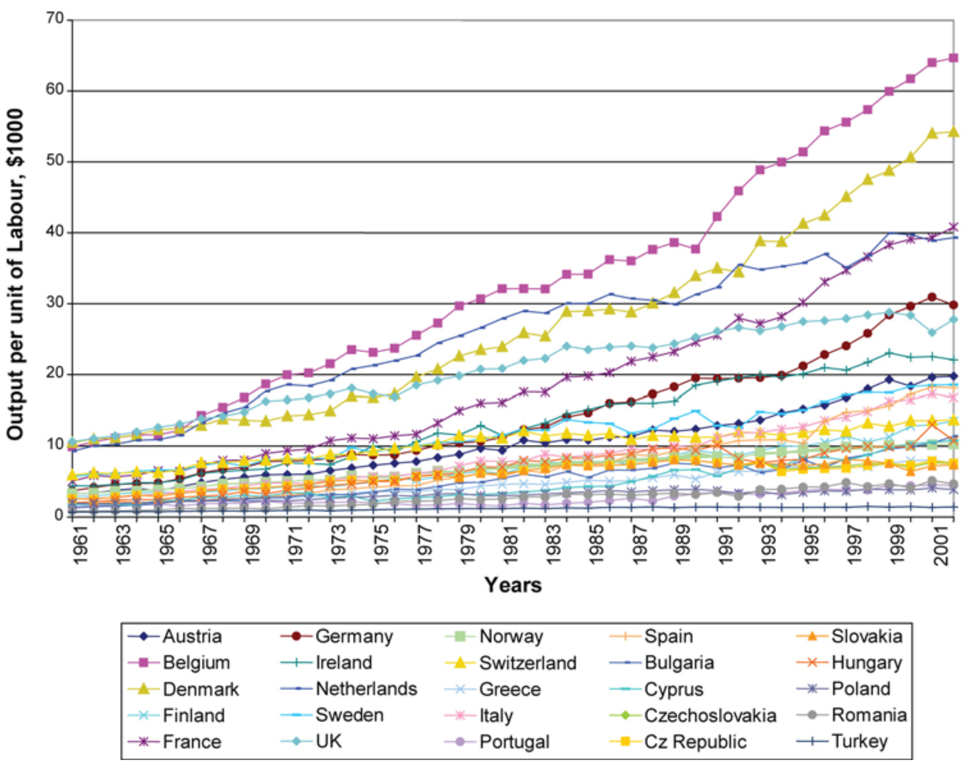

Figure 7.13. Labor productivity for the European Union and entrants
Sources: See Data References Appendix.

$65,000, followed by Denmark, at $54,000. The UK level at $28,000 is just over 50% that of the Danes, but this is still almost triple the levels of the two leading entrants, Bulgaria and Hungary, which are about $11,000 per worker. Notice too, that the growth rates of the leading countries have, if anything, increased, but the UK growth rate slows after 1984. Since labor reduction dominates TFP growth, this turning point will come up again in the TFP section.

Figure 7.14 shows the United Kingdom and the new entrants only, as the larger scale allowed by the smaller dispersion makes the differences clearer. Now it is very clear that the United Kingdom may be well behind the EU leaders, but it is still in a different league from the potential entrants. In turn, even Poland, which is the worst of the Central and Eastern European countries, has output of almost $3,900 per worker, whereas Turkey is still in the emerging economy range at just over $1,400 per worker.

Since the lack of prices and hence factor shares precluded the Tornqvist-Theil approach, the methodology for TFP measurement was to generate the Malmquist index using both data envelopment analysis (DEA) and stochastic frontier estimation. The resulting indexes are shown in Figure 7.15 for the full sample, and the

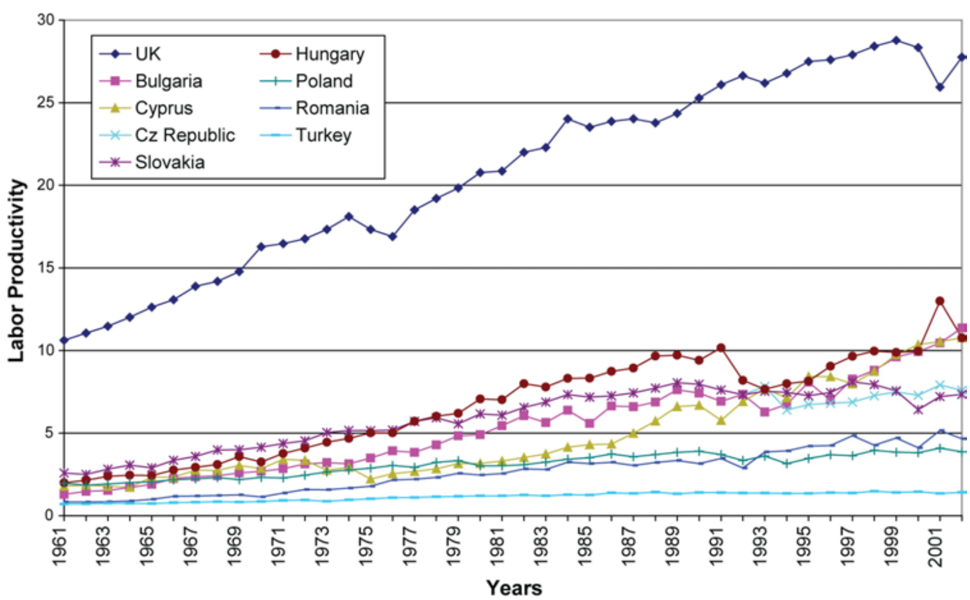

Figure 7.14. Labor productivity in the United Kingdom and potential European Union entrants
Sources: See Data References Appendix.

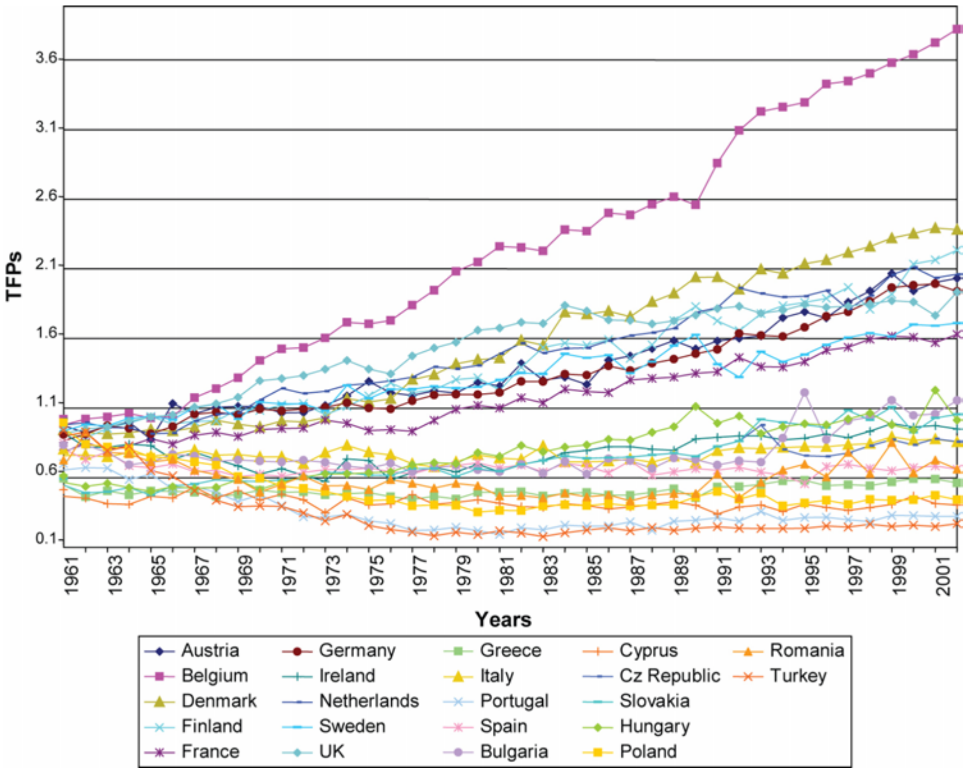

Figure 7.15. Malmquist TFP for the European Union and entrants
Sources: See Data References Appendix.

results are quite clear.[4] There are two distinct groups, with the northwestern EU countries making up the successful upper group and the rest confined to the low TFP growth group. The only exception to this regional division is the Republic of Ireland, which is in the low-growth group, finishing behind Bulgaria, Slovakia, and Hungary, all of which have final values of around 1.1. These are followed by Italy and the Czech Republic, then Romania, Spain, Greece, and Poland, which are still ahead of Cyprus and Portugal, with Turkey consistently last.

Do any of the new entrants seem likely to catch up with the northwest EU group in the foreseeable future? The gap between the leading accession countries (Bulgaria, Czech Republic, Slovakia, and Hungary at 1.1) in 2002 and the last country in the northwest EU group is 0.5. Now compare this with the best progress made by any of the lower group. Hungary has gone from 0.56 to 1.01,

[4]If Belgium, which has the highest levels and growth rates, is excluded, the outcome is clearer because of the larger scale on the graph.

which is a gain of 0.45 in 42 years. Thus, unless there are organizational changes that give massive growth, it seems unlikely that the agricultural sectors of the potential entrants could achieve the TFP levels of the northwest EU group in less than 40 years, or by about 2050. A slightly more sophisticated calculation can be made by looking at a series for each of these countries determining any discernable trend during the last few years and using just these years to estimate growth projections. The results of this exercise are in Table 7.8.

The potential entrant that is in the leading group and has the best growth rate is Hungary, which is growing 2.2% faster than the United Kingdom on these projections. At that differential growth rate, Hungary should catch up in 36 years. Of course, this is a matter of the whole sector catching up, since in this analysis we can only look at all outputs relative to all inputs. This is useful but hardly an adequate answer, especially since the countries in central and eastern Europe have dualistic agricultural systems, to differing extents. If a country has a backward sector of small peasant farmers and co-operatives or formerly state-owned farms that are larger and better endowed with resources, then we need to be able to separate the better enterprises and compare them with UK or U.S. farms. That is why the previous section considered farm-level data.

8. EXPLAINING CHANGES IN UK TFP GROWTH: CAUSES OF THE DECLINE

The UK track record on productivity growth is sufficiently poor that it is worth considering the causes to avoid making the same mistakes. The causes of the decline can be divided into two types: some are an illusion, caused by better measurement of the same reality, while others actually result from real changes.

Table 7.8. TFP growth projections

Country	Years	TFP Growth Rate (%)
United Kingdom	1984-2002	0.39
Bulgaria	1997-2002	1.85
Cyprus	1994-2002	1.67
Czech Republic	1995-2002	2.31
Hungary	1993-1998	2.62
Poland	1994-2001	1.90
Romania	1994-2001	1.25
Slovakia	1993-1999	1.39
Turkey	1995-2002	0.47

Sources: See Data References Appendix.

It is possible that there has not been any decline but only if less conventional measures are used. Thirtle et al. (2004a) reports two cases in which the decline practically disappears, and we begin with these. Then, there are two reasons why the measurements have changed, one due to better data and the other to the increasing appropriability of biological innovations. The main causes of the real decline are then covered, which are the lack of investment in UK agriculture, cuts in public R&D, the effect this had on private sector patents, and the slowing of the growth of farm size. Concerning the effect of the demise of the public extension service in 1988, it is only possible to speculate on the effect. Finally, there are four other possible causes, two that are external to the sector, which are unlikely to have had large effects.

1. Correction of the TFP calculation when technological change is biased. The calculation of TFP assumes that technological change is Hicks neutral (that is, it saves all the inputs in the same proportion as they are being used) and imposes this condition. It has now been shown that when technical change is actually biased, as it is in UK agriculture, this can lead to serious errors in measurement, which get worse over time. Thirtle et al. (2003) and Bailey, Irz, and Balcombe (2004) show that if the factor shares used in aggregation are adjusted to allow for biased technical change, the resulting TFP index shows almost no sign of decline after 1984. Although a paper on this subject won the best contributed paper prize at the meetings of the International Association of Agricultural Economists in 2000, this correction is certainly not yet accepted as conventional wisdom.

2. A social TFP adjusted for environmental externalities. Conventional measures of TFP do not take into account inputs and outputs that are externalities in the production process. Hence these measures do not account for the potentially polluting substances that are produced by agriculture alongside food and other products. These substances include nitrates, pesticides, and greenhouse and other gases, and their emission can potentially contribute to biodiversity loss and climate change, among other negative environmental impacts.

Total social factor productivity is estimated using the conventional productivity measures calculated by Thirtle et al. (2004a) and incorporating emissions of various polluting gases from UK agriculture for the period 1970 to 1999. This new measure showed that total social factor productivity has grown at 1.7% per annum since 1984, as compared with 0.26% for the conventional TFP. This reflects a decline in emissions of polluting gases, as farms have switched fuel types over the period, and since the 1990s, because of the ban on field burning of crop residues.

This is a very sensible outcome, in view of the fact that the reforms of public R&D in the 1980s and 1990s made productivity-enhancing research the responsibility of the industry. Public money was redirected toward the production of public goods, which meant lessening pollution, and increasing countryside stewardship, animal health and welfare, and food safety. Thus, it is hardly surprising that this is where the growth is.

3. Detailed data and quality change. Why would the new DEFRA data give lower growth of TFP than the old data? The quality adjustment reason raised earlier harks back to the important debate that centered on Jorgenson and Griliches's (1967) criticism of Dennison's (1962) growth accounting for the U.S. economy. Dennison showed substantial productivity growth, but this was the residual, not accounted for by inputs, which Jorgenson and Griliches dismissed as measurement error. They argued that if all outputs and inputs were included and correctly measured in efficiency units, thus allowing for quality change, TFP growth should be exactly zero, as inputs must explain outputs. This rests on the notion that all technical change is embodied in inputs, and Jorgenson and Griliches did back down somewhat in later papers. For example, in agriculture, there can be disembodied technical change, due to differences in managerial ability. A better farmer can produce more with exactly the same inputs, by planting, fertilizing, weeding, and harvesting at the right time.

The Jorgenson and Griliches argument is relevant here, since the old MAFF data were far cruder than the new DEFRA data, so there must be a tendency for less of the output to be properly accounted for. The results reported by Barnes (2002) support this supposition. Barnes constructed a TFP directly from the Central Statistical Organization data published in the Annual Abstract of Statistics. This gives very little detail, and he used four output categories and eight inputs. These data were much less detailed than those used by MAFF or Amadi (2000) and the result is that Barnes's TFP fails to show any kind of decline in the 1990s. The annual growth rate of TFP from 1972 to 1995 is 3.25%, which is huge relative to the results based on the old MAFF index, let alone the new DEFRA results.

4. The switch from public to private R&D. It is possible to build on the work of Jorgenson and Griliches (1967) by asking what an agricultural TFP index measures. Most of what it measures are the effects of the technology produced by the public sector and made available almost free of charge. This "public good" is a gift to the private sector input suppliers and for that reason does not get included in attempts at quality adjustment of inputs. This is why Griliches (1964) included public R&D in the production function, but neither he nor Evenson (1967) included private R&D. Thus, as appropriability has improved and the private sector has increased its share of technology generation, now outspending the public sector, the improved technology is more likely to be accounted for in the quality-adjusted input series, which should decline less or grow more rapidly. Thus, measured TFP growth should decline continually as this process advances. If the public sector withdrew completely and quality adjustment of inputs was accurate, Jorgenson and Griliches's claims would prove almost to be true.

5. Lack of investment in UK agriculture. The structural break in UK TFP comes in the mid-1980s, immediately after the peak in public R&D expenditure in 1982. Since the peak effect comes with a lag of 12 or more years and the initial effects tend to be very small or even non-existent (Thirtle, Piesse, and Schimmelpfennig 2008), it seems likely that other real causes need to be examined. A leading candidate, at least according to the agricultural scientists, is the lack of profitability of the sector, which by the mid-1980s was reflected in a lack of investment. This suggestion is worthy of examination, as it must have some credence.

6. Reduction and retargeting of public agricultural R&D. The next three reasons are quantified and can be shown to account for the decline. Thirtle et al. (2004a) showed that TFP growth has actually fallen from 1.68% per annum before 1984 to 0.26% thereafter, and thus there is a reduction of 1.42% to account for. Figure 7.16 shows that public agricultural R&D grew at 6% per annum until 1982, when growth ceased. Then, the fall in TFP follows after two years, which is perhaps too soon to be feasible. The elasticity of 0.13 for R&D reported in Thirtle et al. (2004a) allows a rough calculation of the impact of the R&D cuts on TFP. With R&D growing at 6% per annum this should have accounted for 0.8% per annum of TFP growth, which leaves a further 0.62% to be accounted for.

This section has suggested that TFP growth may also be reduced by the following: using the Tornqvist-Theil index and including the animal capital stocks, but this caused only small reductions; using better data combined with quality adjustment; measurement errors combined with the switch toward private R&D; and ignoring the biases in technological change. The rest of this section adds other possible explanations that could account for the remaining 0.62% per annum of

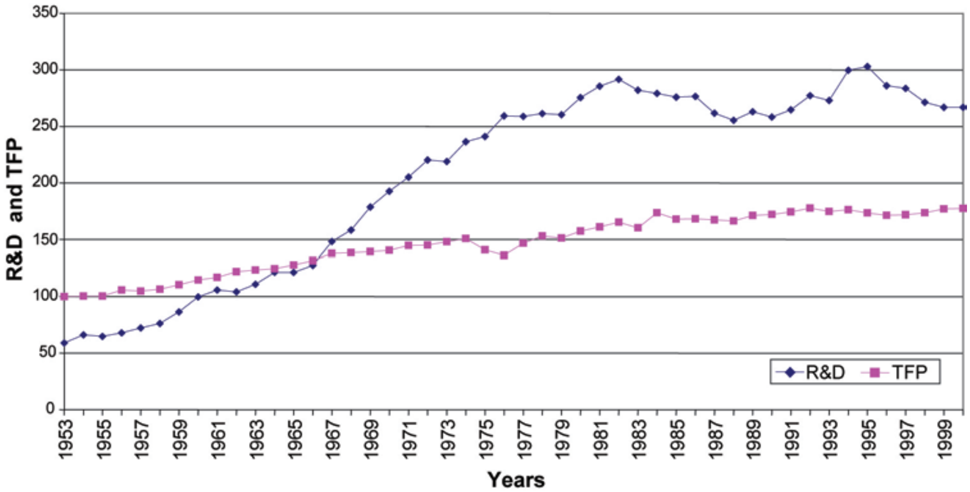

Figure 7.16. Public R&D and TFP
Sources: See Data References Appendix.

lost growth. The first follows from the analysis of the effects of public R&D in the previous section. The Office of Science and Technology (1995) subtitled its *Technology Foresight* publication *Progress through Partnership*. The argument was that technological goals should be achieved through public and private sector collaboration, in which the public institutions produce basic scientific and public interest research and the private sector is responsible for product development, and near-market and productivity-enhancing research. The public sector should provide the scientific base for the applied research and development of the private institutions. The relationship between public and private R&D has been studied, and the usual suggestion is that the two activities are complements. Thus, the reduction in public R&D is highly likely to have reduced private R&D, and this effect also needs to be estimated and taken into account.

In sum, there is strong evidence of market failure and the need for continued and increased public funding of agricultural research. Yet critics of the reforms of agricultural research over the past 25 years have noted that neither the word agriculture nor food appears in the title of the BBSRC, and that DEFRA is no longer involved in promoting more efficient production of food on British farms. This, together with the reluctance of the private sector to fill the gap, makes it difficult to disagree with Spedding's (1984) assertion that publicly funded agricultural research in the United Kingdom no longer exists. The soundness of this situation is unclear. One might ask, for example, on whom will the now very important food industry rely for research on the commodities that constitute its raw materials? The government needs to reconsider policies to better ensure sensible allocation of resources between the public and private sectors. Needless to say, there may be lessons here for the many other governments, such as those of Australia, New Zealand, the Netherlands, and the United States, that have similarly sought to reduce public spending, to shift any remaining funds toward areas in which there is clear evidence of market failure, and to enact legislation promoting greater private funding of agricultural research (Alston, Pardey, and Smith 1999). Yet, the complexity and unequal distribution of the reallocations in the United Kingdom (Thirtle, Palladino, and Piesse 1997) should warn against superficial comparisons of the experience in countries in which agricultural research has historically been organized very differently.

7. Private sector patents. The evidence on recent private sector activity is limited, but there are good data on patents pertaining to agriculture from the Yale Technology Concordance. The first column of Table 7.9 reports the total number of patents granted by the United Kingdom to all the major foreign applicants from 1969 to 1995. The number increases until 1978, when it reaches a peak of 923, before falling to an all-time low of 449 in 1988 and then recovering to its earlier levels by 1995.

The lower numbers coincide with the decline in public R&D, but the patent series declines first, suggesting that the United Kingdom was becoming a less attractive market before the R&D cuts began. The behavior of foreign patent applicants is important, but the key point here is the relationship between UK R&D and UK patents, as the UK patent series is quite different. From 1978 to 1983 the level of UK patents is consistently high, at well over 300. Then, from 1984 onward, the number declines, falling to 70 in 1988, or barely 20% of what it was before the cuts began. This relationship is shown in Figure 7.17. Regressing patents on R&D, with a one-period lag (so that R&D is predetermined and hence weakly exogenous) shows that a 1% reduction in R&D leads to a 1.62% reduction in domestic patents.[5] This suggests that public R&D and domestic patents are complements rather than substitutes, and when the growth of public R&D was cut from 6% per annum to zero, the effect on private activity would have been a reduction of 9.6% (6*1.6). The elasticity of TFP with respect to patents is about 0.07 (from Thirtle et al. 2004a), so this would have reduced TFP

[5]Note that the patents are both private and public, so some of the decline is due to less public sector activity.

Table 7.9. Patents registered in the United Kingdom, by applicant country

Year	Total	All Foreign	UK	U.S.	Germany	Japan	France	Holland	Switzer -land	Italy	GB/ Foreign
1969	542	310	232	115	61	11	31	40	12	5	0.748
1970	883	533	350	176	95	23	40	95	20	5	0.657
1971	827	499	328	157	108	16	56	51	33	9	0.657
1972	816	518	298	170	118	29	37	57	25	12	0.575
1973	716	441	275	150	101	27	39	27	22	11	0.624
1974	664	405	259	126	82	22	38	50	16	11	0.640
1975	806	513	293	177	107	22	43	52	24	9	0.571
1976	780	488	292	148	109	31	64	46	18	5	0.598
1977	769	515	254	147	109	28	39	87	18	9	0.493
1978	923	589	334	169	129	42	40	87	22	6	0.567
1979	845	502	343	153	118	44	38	70	20	7	0.684
1980	767	421	345	138	107	44	36	55	18	9	0.820
1981	688	348	341	123	96	44	34	42	16	9	0.979
1982	610	281	329	108	85	43	32	30	15	10	1.169
1983	532	222	310	93	74	41	29	20	13	10	1.400
1984	515	259	257	84	73	50	29	19	12	10	0.991
1985	499	293	206	75	72	59	30	17	12	10	0.702
1986	482	324	158	67	71	67	30	16	11	11	0.486
1987	465	353	112	59	70	74	31	14	11	11	0.318
1988	449	379	70	51	68	81	31	13	10	11	0.185
1989	476	397	79	65	79	81	35	15	10	13	0.199
1990	658	542	116	105	120	107	52	23	13	20	0.214
1991	530	431	99	96	104	81	44	20	10	17	0.229
1992	557	448	109	114	118	80	49	22	10	19	0.244
1993	584	463	120	132	133	79	54	25	10	22	0.260
1994	733	622	111	185	108	102	50	28	11	23	0.179
1995	883	781	102	237	83	124	46	31	12	25	0.131
Total	**18000**	**11877**	**6122**	3420	2598	1452	1076	1051	426	321	

Sources: See Data References Appendix.

by a further 0.67% per annum. This estimate is a bit crude, but it says that the total effect on TFP of the cut in UK public R&D was 1.47%. Thus, the public R&D cuts and their effects on private activity are alone sufficient to explain the 1.42% reduction in TFP growth. However, there are other possible impacts that need to be considered.

Table 7.9 also suggests that the relationship between UK R&D and patents is negatively related to foreign patents. By 1989, when there are only 79 UK

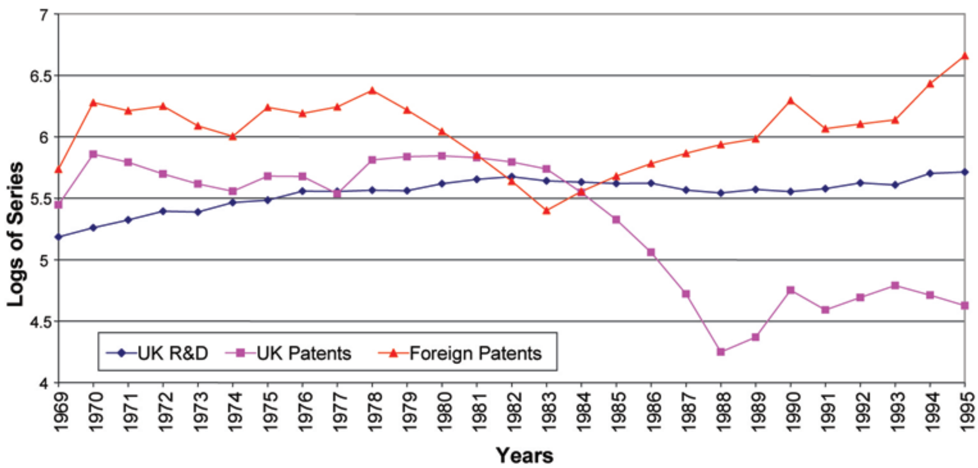

Figure 7.17. Public R&D, UK patents, and foreign patents
Sources: See Data References Appendix.

patents, this figure is matched by the Germans and exceeded by the Japanese, which is quite remarkable. The last column of Table 7.9 shows that whereas UK patents exceeded all foreign patents in 1982 and 1983, by 1995 the United Kingdom was only registering 13% of the number of foreign patents. Thus, it looks as if the demise in UK activity has led to a vast increase in the relative importance of foreign multinational company activity. This is also a result that seems not to have been noted before. It suggests that cutting back the UK R&D effort may well lead to a greater level of foreign technology entering UK agriculture. Imported private sector technology is a substitute for national public and private R&D and may be a partial cure for slow TFP growth. The figures show that from 1983, the result of a 1% reduction in UK patents is a 0.54% increase in foreign patents registered in the United Kingdom. If foreign patents have the same impact on TFP as domestic patents, a further effect of the public R&D cuts would be to increase TFP by 0.22% per annum because of the increase in foreign activity.

8. Farm size. Thirtle et al. (2004a) showed that growth in farm size also affected TFP growth, but the coefficients on the two policy variables were very small indeed. Figure 7.18 shows that farm size practically ceased growing in the 1990s, when the rate fell from 1.0% per annum to 0.1%. The elasticity of 0.21 from Thirtle et al. (2004a) suggests that this cut of 0.9% could have reduced TFP growth by 0.19%. Set this against the extra 0.22% due to foreign activity and the numbers add up almost perfectly to explain the decrease in TFP growth.

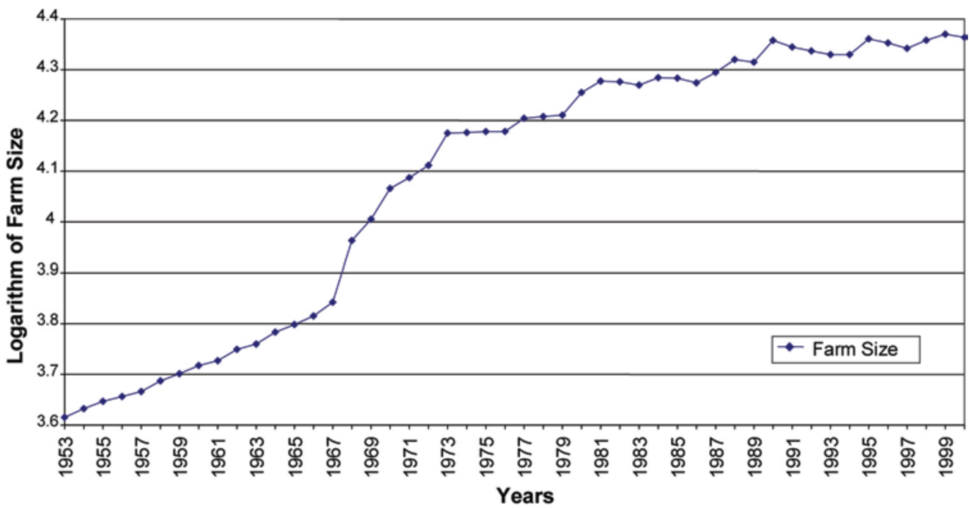

Figure 7.18. Farm size (log scale)
Sources: See Data References Appendix.

9. Extension. Extension expenditures could not be included in this section, because there are no data after 1988, when free public extension services ceased, but it is possible to speculate as to the effects. The conventional wisdom (Thirtle, Piesse, and Turk 1996) suggests that R&D creates technology that moves the frontier forward, while extension spreads the knowledge to farmers to ensure that they adopt the new techniques and stay close to the efficiency frontier. Hadley (2006) used farm-level data to study efficiency change and showed positive technical change but considerable decreases in efficiency as farms fail to keep up with the advancing frontier. These results suggest that the demise of the public extension service has also reduced TFP growth.

10. The long-run growth path. There is reason to believe that past levels of growth cannot be maintained. Jones (1999), in a paper first presented at the Allied Social Sciences annual conference in Chicago in 1998 under the title "The Upcoming Slowdown in US Economic Growth" (Jones 1997), pointed out that the U.S. growth rate from the 1950s cannot be maintained. Rapid growth has been driven by increases in educational levels, increases in research intensities, and increased openness of the world economy. These are all one-off changes, in the sense that it will not be possible to continue doubling the proportion of the population attending universities, which has reached about half, or doubling research intensities, which are already over 20% of sales for high-tech industries like pharmaceuticals. Neither can the world economy be opened up a second time. Thus, Jones showed that the U.S. economy is far from its long-run balanced growth path. His calculations showed that 35% of U.S. growth is attributable to the rise in education levels, 40% to increases in research intensity, and only 25% to the components of long-run growth. Thus, at some stage in the relatively near future, growth must fall from close to 3% per annum to less than 1%.

The same is true of productivity growth in agriculture. Education levels need improving but cannot grow forever, and the multinational input companies must be getting close to the maximum possible research intensities, so TFP growth must slow down in the long run.

11. Asset fixity. There are three other possible causes, which are worthy of mention. One is the well-known proposition that when farmers reduce output, costs will not fall as much as they rose during expansion. Asset fixity and the lack of perfect secondary markets for capital items account for this, and, similarly, TFP growth may be more easily achieved when output is expanding, so that capital is fully utilized and purchased only when needed. When output is contracting, capital goods are likely to be underutilized and the stock can only be reduced at the rate of depreciation. Output data for a sample of countries is needed to test this proposition, but it is obvious from Figure 7.2 that output ceased growing in the United Kingdom in 1984.

12. Convergence. The remaining two possible causes seem to be unlikely. First, regressions to explain TFP in panel data usually include starting values, since catching up tends to be easier than leading. This can hardly apply to the United Kingdom, which has not been a leader in productivity terms for a very long time, and the current leading countries are doing far better.

13. Ozone pollution. Finally, industrial pollution affects yields. There is now substantial evidence that low-level ozone pollution reduces cereal yields, and we suspect that ozone has contributed to the decline in yields in other crops. The plant biologists have conducted controlled experiments on cereal yields, which show that low-level ozone pollution levels that are not damaging to human health severely affect crop yields. Experiments in the United Kingdom show that ozone dispersion is wide, so most areas are affected, and yields are reduced. However, although the plant breeders have not recognized the problem, their trial plots are in affected areas, and they have inadvertently limited the damage by selecting ozone-tolerant varieties. The evidence to date (Shankar and Neeliah 2005; Kaliakatsou, Thirtle, and Bell forthcoming) suggests that the yield losses due to ozone are no more than about 2%-3%. Also, the United Kingdom is no more affected than other EU countries, so it is unlikely that this can be the cause of its relatively poor performance in terms of yield growth, which was noted earlier.

9. CONCLUSION

This chapter began with a brief review of policy changes in UK agriculture, changes that are used later in explaining technical and efficiency change at the farm level. The history of yield changes in the United Kingdom shows that the notion of an agricultural revolution from about 1750 is too simplistic. There were more prior changes of perhaps equal consequence. What is beyond doubt is that the massive increase in the growth rate of yields only occurs with the application of modern science after WWII. However, in the United Kingdom the increase in yield growths from the historical rate of around 0.2% per annum to 2% per annum lasted less than half a century. Since 1996, cereal yield growth is actually lower than between 1885 to 1945.

In the period beginning in 1953, for which good data are available, yields, output, and TFP grew at unprecedented respective rates of 2.08%, 1.87%, and 1.67% until 1984. Since 1984, output and yields have fallen slightly, and TFP grew at an average of only 0.3% until 1996. Since then, TFP has increased to 1.2% growth per annum. Only labor productivity has continued to grow really rapidly, at 3.86% per annum until 2000, and at 6.4% since that date. However, we question this last figure as there is no substitution of machinery, equipment, and buildings. Indeed, all the capital inputs have declined since the mid-1990s following reported low levels of investment from the mid-1980s. These declines are thought to be a cause of the United Kingdom's recent poor productivity growth, so the big jump in labor productivity suggests possible undercounting of workers from the new EU member states and elsewhere.

The aggregate TFP suffers from the limitation of ignoring variance across regions, crops, and farms, which limits its usefulness for comparisons of competitiveness. Thus, the next step is to consider crop- and region-specific TFPs for the eastern counties of England, which is the prime arable area. The TFP for sugar grew considerably faster than the aggregate UK index, and the eastern counties' aggregate index for sugar, oilseed rape, wheat, barley, and potatoes grew at 2.87% per annum as compared with 1.5% per annum for the UK average for the same period. Crop-specific TFP growth rates varied from 5.8% for oilseed rape to 1.19% for potatoes.

The farm-level studies of the United Kingdom decompose the rates of technical change and efficiency change, which both vary with farm type. They show that while there has been substantial technical progress, average farm-level efficiencies have fallen, which means that the laggards are not keeping up and will drag down average productivity. This suggests that the demise of free extension advice may be a factor in poor productivity growth. The analysis at the farm level also contributes to our understanding of TFP change by measuring the effects of policy changes and exogenous shocks such as animal disease epidemics, like BSE, and by showing the variance in efficiency within farm types. The variance in efficiency across farms needs to be kept in mind when comparing aggregate TFP levels as a guide to competitiveness.

Productivity comparisons between the EC-10 countries and the United States show that the United States does tend to have higher productivity than its nearest European rivals. However, Section 8 shows that there are other factors involved in competitiveness. Productivity comparisons across the EU countries, intended to assess the impact on UK agriculture at the accession of new member states, show that UK yields were actually lower than those of the leading new members such as Hungary, Poland, and the former Czechoslovakia. However, labor productivity and TFP was much higher for the United Kingdom and other incumbent EU member states. A rough estimate of the time it will take for fast-growing Hungary to catch the United Kingdom in TFP is 36 years.

These aggregates conceal the fact that the best producers in these countries are way above the national averages and are more productive than the bottom end of the UK farm distribution. Particularly, agriculture in countries like Hungary is dualistic, with some large, modern, efficient farms using the latest technology, while the majority of small-holding farms are backward and drag the average way down. Thus, aggregate TFP and even the competitiveness study reported in this paper are of dubious value in predicting the exporting ability of some emergent European countries.

Even so, the competitiveness of the United States, taking input prices and exchange rates into account, as well as TFP, is normally better on average than even the leading EU countries. The exceptions are brief periods in the early 1970s and mid-1980s, when Denmark, Belgium, and Germany had a slight aggregate price advantage.

The last section of the chapter considers the reasons why the UK's TFP performance has been so poor. Clearly, the United Kingdom dropped from one of the better EU countries in TFP terms to sharing last place with Sweden, until the recent accession of new members that have far lower TFP levels. The United Kingdom's failure in this area has been well recorded and should serve as a warning that the agricultural sector does need public support, or some viable alternative means of producing public goods to support farmers.

APPENDIX A: DATA SOURCES

Figure 7.1: Crop Yields

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Table 7.4 and Figure 7.2: Output, Input, TFP, Yield, and Labor Productivity Indexes

1953-2000: Thirtle, C., L. Lin, J. Holding, and L. Jenkins. 2004. "Explaining the Decline in UK Agricultural Productivity Growth." *Journal of Agricultural Economics* 55(2): 343-66.

2000-2008: DEFRA. Various editions and online. *Agriculture in the United Kingdom*. London: Her Majesty's Stationery Office.

Table 7.6 and Figures 7.3-7.6: Individual Output and Input Shares and Volume Indexes

1953-2000: Thirtle, C., L. Lin, J. Holding, and L. Jenkins. 2004. "Explaining the Decline in UK Agricultural Productivity Growth." *Journal of Agricultural Economics* 55(2): 343-66.

2000-2008: DEFRA. Various editions and online. *Agriculture in the United Kingdom*. London: Her Majesty's Stationery Office.

Figure 7.7: Sugar TFP

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Figure 7.8 and Table 7.7: Eastern Counties TFP and Its Decomposition

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Figures 7.9-7.15 and Table 7.8: Productivity Comparisons for the EU and Acceding States

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Piesse, A. Kasterine, and G. Brooks. 2004. *Impact on UK Agriculture of Increasing Agricultural Productivity in EU Acceding Countries.* London: Final Report to DEFRA.

Table 7.9 and Figures 7.16-7.18: Explaining TFP—R&D, TFP, Patents, and Farm Size

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CHAPTER 8

Shifting Patterns of Agricultural Production and Productivity in the United States

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1. INTRODUCTION

The structure of U.S. agricultural production changed dramatically during the twentieth century. The changes were associated with major technological innovations that transformed the relationship between agricultural inputs and outputs, contributing to rapid increases in agricultural productivity. In this chapter we examine trends and major structural changes in input use and the resulting changes in agricultural outputs and productivity in the United States over the past 100 years. Our detailed analysis emphasizes the years since the Second World War and gives attention to the spatial patterns of changes in agricultural

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input use, outputs, and productivity that are concealed by consideration of the aggregate national data alone.[1]

As in many other places around the world during the twentieth century, in the United States productivity grew relatively rapidly in the agricultural sector compared with other sectors of the economy. As stated by Jorgenson and Gollop (1992, p. 748): "There is little doubt that productivity growth is the principal factor responsible for postwar economic growth in agriculture, accounting for more than 80% of the sector's growth. This contrasts with 13% and 25% levels for productivity's contribution to economic growth in the private nonfarm economy and manufacturing, respectively." However, this "golden age" of agricultural productivity growth may have ended. Evidence is mounting that suggests we have entered a new era, with substantially lower rates of productivity growth. The chapter concludes with an analysis of rates of productivity growth for different periods, finding a statistically significant slowdown in productivity growth after 1990.

2. MEASURES OF INPUTS, OUTPUTS, AND PRODUCTIVITY

The main analysis in this chapter uses data developed under the leadership of Philip Pardey at the University of Minnesota's International Science and Technology Practice and Policy (InSTePP) center as a joint effort with colleagues now at Oberlin College (Barbara Craig), the University of Wyoming (Matt Andersen), and the University of California, Davis (Julian Alston). The InSTePP production accounts consist of state-specific measures of the prices and quantities of 74 categories of outputs and 58 categories of inputs for the 48 contiguous U.S. states. The input series covers the period 1949-2002 while the output series runs from 1949 to 2006. This version of the data represents a revised, expanded, and updated version of the series published by Acquaye, Alston, and Pardey (2003), which ran from 1949 to 1991. Here we provide a brief overview of the InSTePP production accounts, emphasizing some of the more important data construction choices used to assemble the series. More complete details can be found in Pardey et al. (2009).

In developing the InSTePP data, special attention was given to accounting for variation in the composition of input and output aggregates, with particular reference to the quality of inputs (and outputs) and the spatial dimension. Star (1974) showed that it is safe to use pre-aggregated data only if all of the inputs

[1]This chapter is based on work in the book by Alston, Andersen, James, and Pardey (2010), especially Chapters 2 through 5. Those chapters provide more complete details on data and sources, and more complete analysis of the issues raised and discussed in summary terms here.

(and outputs) in the class are growing at the same rate or are perfect substitutes for one another. If, for example, the rate of growth of the higher-priced inputs (outputs) exceeds the rate of growth of the lower-priced inputs (outputs), the estimated rate of growth of the group will be biased downward when pre-aggregated data are used. Hence, growth rates of agricultural productivity will tend to be overstated if the quantities of higher-priced (i.e., higher-quality) inputs are growing relatively quickly.

Here, the 58 categories of inputs are grouped into four broad categories: land, labor, capital, and materials inputs. The land input is subdivided into service flows from three basic types of land, namely, pasture and rangeland, non-irrigated cropland, and irrigated cropland. The price weights used for aggregation of the land input are annual state- or region-specific cash rents for each of the three land types. The labor data consist of 30 categories of operator labor by age and education cohort, as well as family labor and hired labor. State-specific wages were obtained for the hired and family labor, whereas implicit wages for operators were developed using national data on income earned by "rural farm males," categorized by age and educational attainment.

Capital inputs include seven classes of physical capital and five classes of biological capital. A physical inventory method, based on either counts of assets purchased or on assets in place, was used to compile the capital series as described in some detail in Andersen, Alston, and Pardey (2009) and Pardey et al. (2009).[2] In addition, we adjusted inventories of the physical capital classes to reflect quality change over time depending on the nature of the data available and the service flow profile of each capital type. Rents for capital items were taken to be specific fractions of the purchase price, fractions that varied among capital types. Purchase prices were assumed to reflect the expected present value of real capital services over the lifetime of the specific type of capital.

Eleven types of materials inputs are included in this data set. Apart from fertilizers, measured as quantities of elemental nitrogen, phosphorous, and potash, the purchased input quantities were implicit quantities derived by dividing state-specific expenditure totals by the corresponding national average price. The mis-

[2]The capital series was identified as a particular source of discrepancies between the InSTePP measures of multi-factor productivity growth and the counterpart measures published by the USDA (see, for instance, Ball, Butault, and Nehring 2001). These discrepancies are more pronounced for particular states and subperiods than for the aggregate U.S. series over the full period for which both measures are available (see Andersen, Alston, and Pardey 2009 for details and discussion).

cellaneous category was pre-aggregated and included a list of disparate inputs, such as fencing, irrigation fees, hand tools, veterinary services, and insurance costs, among others. In this category, state-specific prices were available only for electricity; all other input prices were national prices or price indices based on national prices paid by farmers.

In the disaggregated form, the output data cover 74 output categories, including 16 field crops, 22 fruits and nuts, 22 vegetables, implicit quantities of greenhouse and nursery products, 9 livestock commodities, and 4 miscellaneous items that include implicit quantities of machines rented out by farmers, and Conservation Reserve Program (CRP) acreage. The prices used as weights to form aggregate output are state-specific prices received by farmers for all commodities, except machines for hire and greenhouse and nursery products. Table 8.1 summarizes the input and output variables and their groupings into various categories. Table 8.2 summarizes the groupings of states into the regions used in this chapter.

The major sources of the price and quantity data for agricultural outputs are annual estimates from the Economic Research Service (ERS) and National Agricultural Statistics Service (NASS) of the U.S. Department of Agriculture (USDA). The estimates come principally from two publications, *Agricultural Statistics* and *Statistical Bulletins*, supplemented with NASS and USDA occasional commodity reports. The output price and quantity data are all state- and commodity-specific except for the "machines hired out" category, which uses a national average price.

The agricultural input data come from a host of sources, including and most importantly from various issues of the U.S. Census of Agriculture. Most of the input data are constructed using Census estimates that are supplemented with annual data from numerous other sources, including the USDA-ERS, the Association of Equipment Manufacturers (AEM), and the Census of Population. For example, Census estimates of operator labor on farms were disaggregated by age and education cohort using data from the ERS Agricultural Resource Management Survey. Also, Census data on the counts of tractors and combines used in production were disaggregated into different horsepower and width classifications using proprietary data from the AEM.

Bias from the procedure used to aggregate inputs and outputs can be kept to a minimum by choosing an appropriate index, carefully selecting value weights for all inputs and outputs, and disaggregating inputs and outputs as finely as possible. The InSTePP indexes of quantities and prices of output and input, as used here, were formed using a Fisher discrete approximation to a Divisia index

Table 8.1. InSTePP input and output classes

Input and Output Categories	Subcategory	Details
Inputs (58)		
Land (3)	Cropland	
	Irrigated cropland	
	Pasture and Grassland	
Labor (32)	Family Labor	
	Hired Labor	
	Operator Labor (30)	Thirty classes characterized by the following: Education: 0-7 years, 8 years, 1-3 years of high school, 4 years of high school, 1-3 years of college, 4 years or more of college Age: 25-34, 35-44, 45-54, 55-64, 65 or more years of age
Capital (12)	Machinery (6)	Automobiles, combines, mowers and conditioners, pickers and balers, tractors, trucks
	Biological Capital (5)	Breeding cows, chickens, ewes, milking cows, sows
	Buildings	
Materials (11)		Electricity, purchased feed, fuel, hired machines, pesticides, nitrogen, phosphorous, potash, repairs, seeds, and miscellaneous purchases
Outputs (74)		
Crops (61)	Field Crops (16)	Barley, corn, cotton, flax, field beans, oats, peanuts, rice, rye, sugar beets, sugarcane, sorghum, soybeans, sunflowers, tobacco, wheat
	Fruits and Nuts (22)	Almonds, apples, apricots, avocados, blueberries, cherries, cranberries, grapefruit, grapes, lemons, nectarines, oranges, pears, peaches, pecans, pistachios, plums, prunes, raspberries, strawberries, tangerines, walnuts
	Vegetables (22)	Asparagus, bell peppers, broccoli, carrots, cantaloupes, cauliflower, celery, cucumbers, garlic, honeydews, lettuce, onions, peas, potatoes, snap beans for processing, spinach (processed), sweet corn (fresh and for processing), sweet potatoes, tomatoes (fresh and for processing), watermelons

Table 8.1. Continued

Input and Output Categories	Subcategory	Details
	Nursery and Greenhouse Products (1)	Aggregate of nursery and greenhouse products
Livestock (9)		Broilers, cattle, eggs, hogs, honey, milk, sheep, turkeys, wool
Miscellaneous (4)		Hops, mushrooms, machines rented out, Conservation Reserve Program acreage

Note: Numbers in parentheses indicate the number of items in each category.

Table 8.2. Regional groupings of states

Region	States in Region
Pacific	California, Oregon, Washington
Mountain	Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, Wyoming
Northern Plains	Kansas, Nebraska, North Dakota, South Dakota
Southern Plains	Arkansas, Louisiana, Mississippi, Oklahoma, Texas
Central	Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, Wisconsin
Southeast	Alabama, Florida, Georgia, Kentucky, North Carolina, South Carolina, Tennessee, Virginia, West Virginia
Northeast	Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont

for the years 1949 through 2002. An index of multifactor productivity (MFP) for each state and region and the nation was then constructed as the ratio of the index of aggregate output to the index of aggregate input. Estimates of annual productivity growth were constructed as logarithmic differences.

3. AGRICULTURAL INPUTS: TRENDS AND STRUCTURAL CHANGES

During the twentieth century, revolutionary technological advancements transformed inputs such as seed, fertilizers, and agricultural chemicals, and the "quality" of agricultural inputs—notably capital, labor, and land—increased generally, especially during the latter half of the century. The apparent decline in the use of conventional agricultural inputs, particularly over recent decades and especially of labor, is offset somewhat when we account properly for the changing composition and quality of inputs over time. For example, farmers are much better educated and more experienced on average compared with 50 years ago, and a higher proportion of cropland is irrigated. Identifying these important structural changes in the nature of inputs helps construct an informative picture of U.S. agricultural production and the sources of output growth during the twentieth century, particularly developments during the period after World War II.

During the period 1949 to 2002, while the quantity of U.S. agricultural output grew by nearly 250%, the aggregate input quantity declined marginally—even after adjusting for quality changes, which typically consisted of improvements in the quality of inputs.[3] This aggregate trend was the net effect of a large increase in the quantity of materials inputs, a very large decrease in labor inputs, and little or no trend in inputs of services from land and services from capital stocks (Figure 8.1).

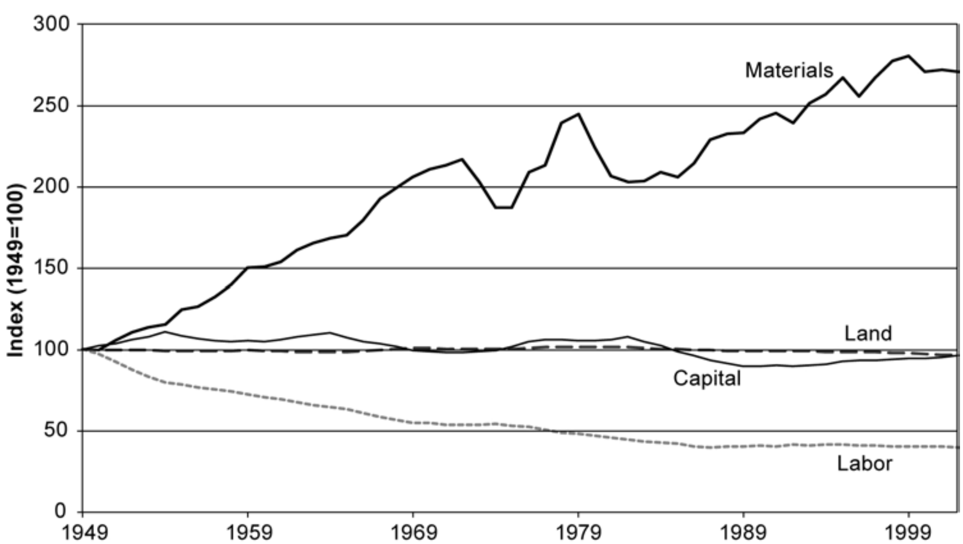


Figure 8.1. Quantity of capital and land services, labor, and materials inputs used in U.S. agriculture, 1949-2002

Source: Alston et al. 2010, based on InSTePP data.
Note: Fisher index of input quantity aggregates indexed at 1949 = 100.

[3]As Star (1974, p. 129) observed, "The great advantage of using disaggregated data is that *quality changes are transformed into quantity changes*" [emphasis in the original]. In the same article he also observed that "in order to be able to add together different units of items, the items must be homogenous: each unit must be a perfect substitute for any other unit, i.e., the marginal rate of substitution is constant and the units of measurement are chosen so that the marginal products of every unit are equal" (p. 125).

Over the period 1949 to 2002, the aggregate quantity of input fell at an average rate of 0.11% per year for the United States as a whole, but rates of change in input use were widely dispersed around this average. In fact, as Figure 8.2 (Panel a) reveals, states were fairly evenly distributed around the mean of this distribution: 22 (46%) of the states had an input growth rate above this national average rate; and of these states, 15 (31%) experienced an overall increase in input use during this period. However, the dispersion among states in the rate of growth of aggregate input use is not at all representative of the dispersion among states in growth rates for specific categories of inputs. Relative to the distribution of total input growth rates, the distribution of growth rates for labor is positioned to the left (with all of the states experiencing a decline in aggregate labor use) and the distribution for materials is to the right (with 90% of the states increasing their use of materials inputs), while the capital and land distributions indicate that 63% and 50% of the states reduced their use of land and capital services inputs, respectively.

Figure 8.3, Panel a, shows the input-use paths of selected states. Aggregate input use grew fastest in Florida (1.18% per year from 1949 to 2002) and declined the most in Massachusetts (shrinking by 1.99% per year, such that aggregate input use in 2002 was just 35% of the 1949 amount). Minnesota's pattern was characteristic of the midwestern states, tracking the national trend fairly closely. The Northeast region experienced the slowest growth in materials inputs and the fastest decline in the use of land, labor, and capital of all the regions in the United States (Figure 8.3, Panel b). The rates of decline in labor use were most pronounced in the Southeast and Northeast regions. The Pacific region, dominated by developments in California, increased its use of materials and capital inputs the fastest and had the smallest rate of decline in the aggregate use of labor. After adjusting for quality-cum-compositional changes, notably those brought about by the growth in irrigated acreage, measured land use grew by 0.25% per year in the Northern Plains and by 0.02% per year in the Mountain region but declined across the 48 states. Likewise, even after adjusting for the changing composition of capital services used in U.S. agriculture (in particular factoring in the changes in vintage, durability, and quality of the machines used on farms), aggregate capital use declined by 0.67% and 0.51% per year in the Northeast and Central regions respectively.

Aggregating among all measured inputs, the quantity of total input use in U.S. agriculture changed little in well over half a century. In contrast, the composition of input use changed dramatically, with U.S. agriculture now much more

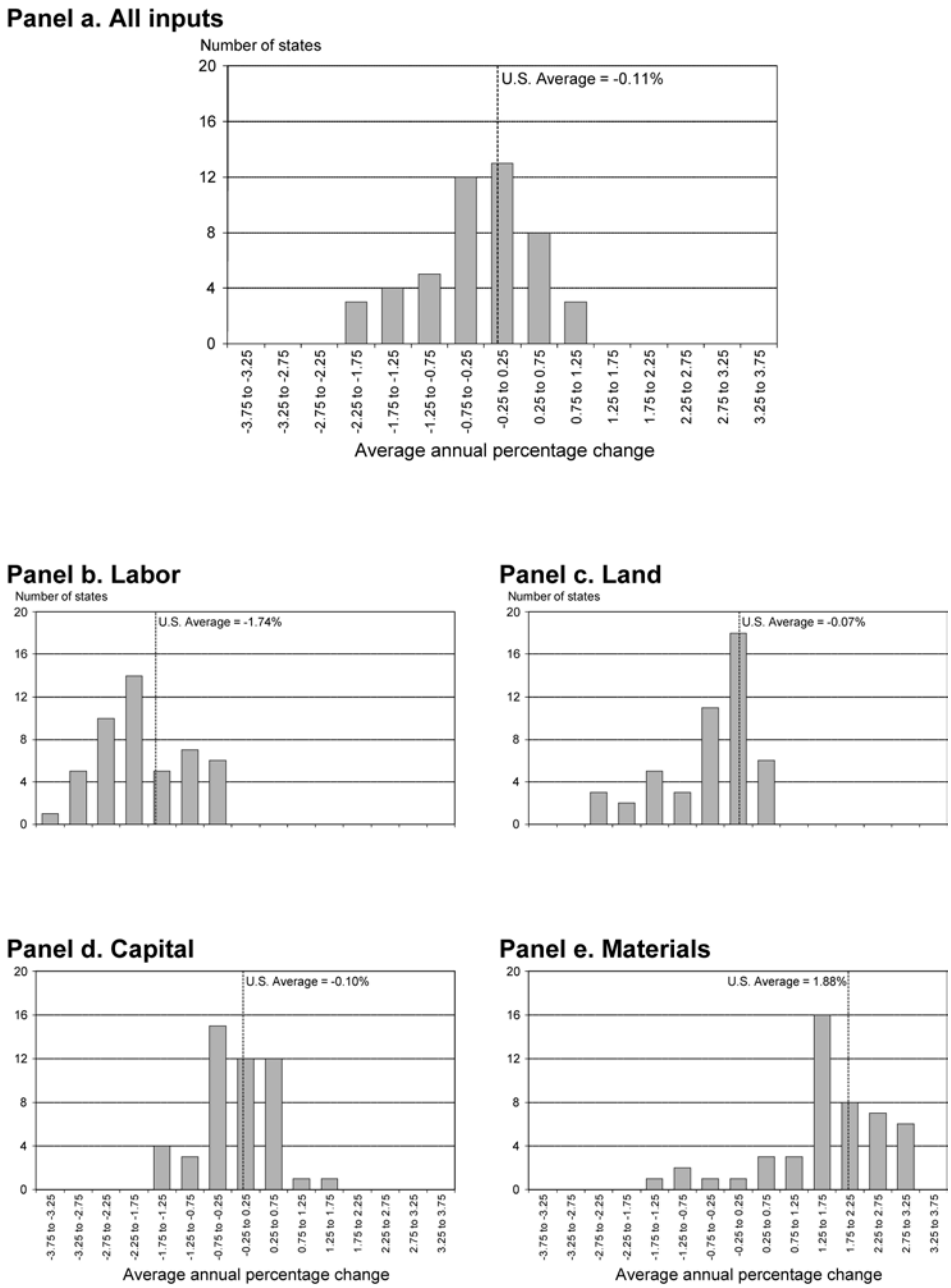
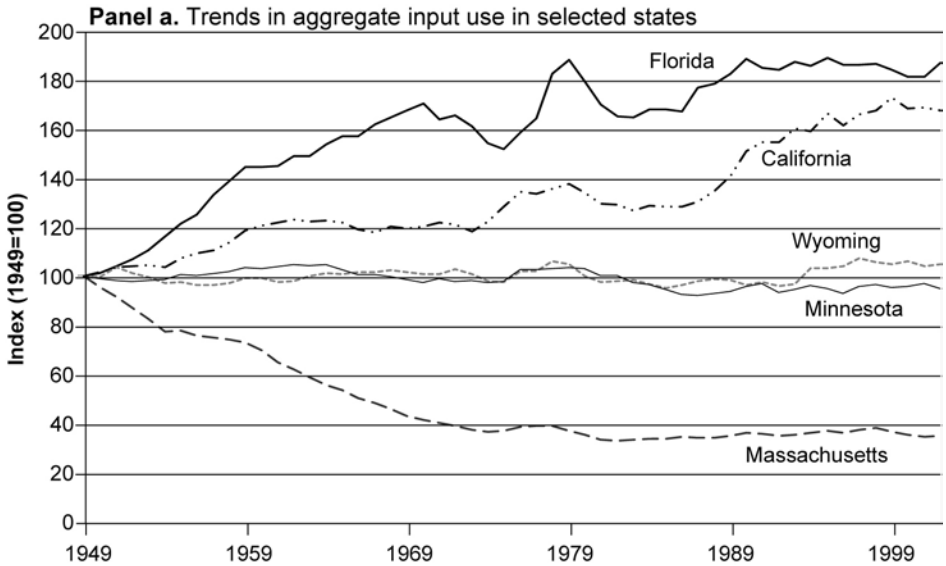


Figure 8.2. Distribution among states in the growth of input use, 1949-2002

Source: Alston et al. 2010, based on InSTePP data.



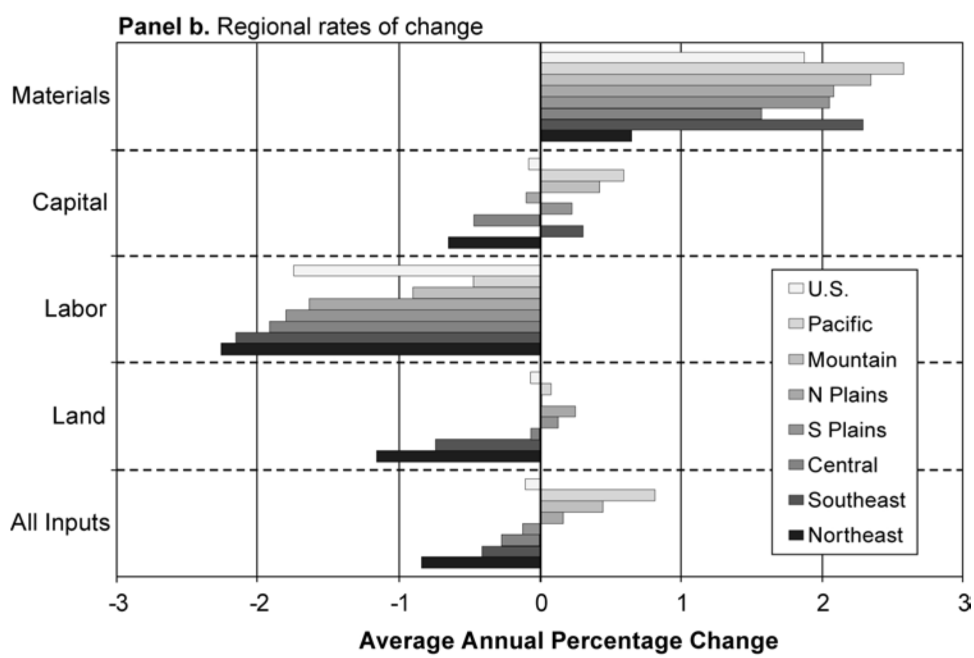


Figure 8.3. State and regional patterns of changes in input use, 1949-2002

Source: Alston et al. 2010, based on InSTePP data.

Note: Regional rates of change represent the average annual rates of growth of regional input quantity indexes, 1949-2002.

reliant on materials inputs purchased off farm and less reliant on labor. Total use of land and capital inputs was about the same in 2002 as it was in 1949. And, while aggregate labor use has declined substantially, the labor used in agriculture is now very different. A much greater proportion of the labor consists of hired workers with much less operator and family labor. Moreover, those farm operators remaining in agriculture are generally older and much more educated than they were decades ago. The spatial structure of aggregate input use in U.S. agriculture also has changed markedly, especially over the past 50 years or so. The spatial pattern of use of individual inputs has changed even more dramatically.

4. AGRICULTURAL OUTPUTS: TRENDS AND STRUCTURAL CHANGES

U.S. agricultural production grew rapidly over the past 100 years, with concomitant marked changes in the composition and location of production. The total nominal value of U.S. agricultural production grew from $12.3 billion in 1924 to $229.1 billion in 2005 (equivalent to compound growth of 3.6% per year). In real terms, the growth rate in the value of production was much slower. Over the period 1929-2005 the implicit price deflator for GDP grew by 3.0% per year. The value of U.S. agricultural production has varied over space and time, reflecting the impacts of changes in prices and quantities of inputs and outputs, and changes in technologies, and the host of factors that directly or indirectly affect these variables. In this section we present a brief summary of the long-term trends, followed by a more detailed look at the more recent period for which we have more detailed data: 1949-2006. The analysis includes a consideration of the changing mix of outputs among states and over time, as well as changes in the value of the output.

While the value of agricultural output grew overall, regional and state shares had not changed much by the middle of the twentieth century. Changes in domestic and export demand as well as changes in off-farm technology contributed to changes in the composition of demand for U.S. agricultural output, which in turn contributed to the changes in the composition and location of production. The shifting geography of population (as well as a substantial migration off farms)—combined with improved communications, electrification, transportation, and logistical infrastructure, which meant that perishables and pre-prepared foods could be moved efficiently over much longer distances—also contributed to this changing spatial pattern of production in the second half of the twentieth century. Substantial on- and off-farm technological innovation underpinned much of these changes.

During the second half of the 20th Century, U.S. agricultural production shifted generally south and west and became more spatially concentrated. In the mid-1920s, Texas and Iowa were the largest states in terms of agricultural production (with an average of 6.9% and 6.7% of the 1924-26 value of U.S. production, respectively). The Central region produced around one-third of the entire U.S. agricultural output at this time. This region includes Iowa and Illinois (then the third-largest producer with a state share of 5.5%) along with the rest of the heartland of the United States. California was the third-ranked state in the mid-1920s, with 5.4% of national production. The regional shifts were substantial. The Central region lost some ground (averaging 27.0% of the total value of output in the 2003-05 period compared with 32.4% in 1924-26), while the Northeast region's share of national agricultural output fell more markedly, from 11.2% in 1924-26 to 6.2% in 2003-05. The biggest increase was in the Pacific region, whose share more than doubled over the almost 80 years since 1924-26 to average 18.3% of U.S. agricultural output in 2003-05. Part of the shift south and west in the value of production was a quantity effect, but part was a move to a larger share of higher-valued output nationally, combined with a massive increase in the share of that higher-valued output being produced in the Pacific region. In the mid-1920s, the Pacific region produced 29% of the country's specialty crops (including fruits, vegetables, and ornamental crops); by the beginning of the twenty-first century that share had grown to more than 50% (Table 8.3).

Over the almost 80-year period from the mid-1920s to 2003-05, for all the output categories in Table 8.3, the share of national output from the Northeast region declined, and by 2003-05 this region produced just 6.2% of the total U.S. value of agricultural production. The Central region produced a much larger share of U.S. output of "other crops" (including field crops such as corn, soybeans, and wheat), up from 24.3% in the mid-1920s to almost 44% by 2003-05, such that "other crops" accounted for 51% of the region's total agricultural output. Livestock production moved strongly out of the Central and Northeast regions to become increasingly concentrated in the Southern Plains and Southeast.[4]

Table 8.4 shows summary information for the outputs included in the data set. Along with the averages of annual values over the period of the data set (from 1949 to 2006), for each of the variables the average annual percentage changes are

[4]Chapter 2 of this volume documents the spatial relocation of production from a global perspective.

Table 8.3. Regional production shares: three-year averages centered on 1925, 1949, and 2004

	Regional Shares of National Commodity Group Production Value				Commodity Group Shares of Regional Production Value		
	Total	Specialty Crops	Other Crops	Livestock	Specialty Crops	Other Crops	Livestock
				(percentage)			
Pacific							
1924–1926	7.8	28.8	2.9	6.7	47.0	16.3	36.7
1948–1950	9.8	36.1	5.7	6.8	43.8	23.4	32.8
2003–2005	18.3	51.8	6.7	10.0	63.3	11.6	25.1
Mountain							
1924–1926	5.6	5.5	4.5	6.8	12.5	35.3	52.2
1948–1950	6.2	7.9	5.7	6.2	15.1	36.8	48.1
2003–2005	7.8	6.4	5.8	10.0	18.2	23.1	58.7
Northern Plains							
1924–1926	12.1	1.3	12.5	15.0	1.4	45.7	52.9
1948–1950	10.7	1.7	14.0	10.2	1.9	52.8	45.3
2003–2005	11.4	1.2	18.4	11.5	2.4	50.9	46.7
Southern Plains							
1924–1926	14.8	6.4	25.2	6.6	5.5	75.4	19.1
1948–1950	13.2	6.0	18.6	10.4	5.4	56.8	37.8
2003–2005	14.0	5.3	13.3	18.6	8.5	30.0	61.4
Central							
1924–1926	32.4	18.3	24.3	45.1	7.2	33.2	59.6
1948–1950	35.8	14.4	34.6	42.2	4.8	38.9	56.3
2003–2005	27.0	8.8	43.7	24.3	7.3	51.1	41.6

Table 8.3. Continued

	Regional Shares of National Commodity Group Production Value				Commodity Group Shares of Regional Production Value		
	Total	Specialty Crops	Other Crops	Livestock	Specialty Crops	Other Crops	Livestock
				(percentage)			
Southeast							
1924–1926	15.9	16.1	25.0	6.5	12.9	69.6	17.5
1948–1950	14.4	15.5	18.2	11.0	12.8	50.8	36.3
2003–2005	15.4	18.0	9.8	17.9	26.2	20.1	53.7
Northeast							
1924–1926	11.2	23.7	5.7	13.3	27.0	22.3	50.7
1948–1950	9.9	18.5	3.3	13.3	22.4	13.3	64.3
2003–2005	6.2	8.5	2.3	7.7	30.8	11.5	57.7
United States							
1924–1926	100.0	100.0	100.0	100.0	12.8	44.3	42.9
1948–1950	100.0	100.0	100.0	100.0	11.9	40.3	47.8
2003–2005	100.0	100.0	100.0	100.0	22.3	31.5	46.1

Sources: Alston et al. 2010 based on InSTePP data files along with Johnson 1990, USDA various years *Agricultural Statistics*, USDA-ERS 2007, U.S. Bureau of the Census 1956-1991, and USDA-NASS 2000-2009.

Notes: The value of production dataset covers 194 commodities for the period 1924 to 2005. For 73 commodities we used price and quantity data from the cited USDA sources. Most of the quantity data are reported quantities produced per state, and the price data are state-specific prices received on farms. For 139 commodities that are almost wholly sold off farm, we used cash receipts (i.e., sales) data to represent value of production, where the implied price data represent farm-gate or first-point-of-sale measures and the implied quantity data are marketings. Data for the greenhouse nursery and marketing category constitute cash receipts from 1924 to 1948, and for 2005. For all other years, InSTePP data assembled from multiple other USDA sources were used.

Table 8.4. Summary of production by output category, average of annual values, 1949-2006

Output	Value (billions 2000 $) (1)	Share of Total Value (%) (2)	Number of States with Value > 0 (3)	Number of States with Value > 1% (4)	Share (%) of Production from Top 4 States (5)	Share (%) of Production from Top 10 States (6)
	(average annual percentage change in parentheses)					
Livestock (9 outputs)	**91.5 (-0.19)**	**48.0 (-0.27)**	**48 (0.00)**	**31 (0.06)**	**27 (0.07)**	**51 (-0.01)**
Cattle	32.7 (0.47)	17.0 (0.39)	48 (0.00)	30 (-0.18)	35 (0.67)	61 (0.33)
Milk	25.0 (-0.55)	13.1 (-0.63)	48 (0.00)	26 (-0.54)	40 (0.72)	64 (0.42)
Hogs	15.4 (-1.23)	8.0 (-1.31)	48 (0.00)	17 (-0.59)	53 (0.46)	80 (0.28)
Field Crops (16 outputs)	**72.0 (-0.28)**	**37.2 (-0.36)**	**46 (-0.11)**	**28 (-0.35)**	**33 (0.45)**	**59 (0.37)**
Corn (grain)	24.6 (0.12)	12.7 (0.04)	43 (-0.28)	17 (-0.39)	55 (0.39)	81 (0.25)
Soybeans	13.5 (3.06)	6.8 (2.98)	30 (0.12)	16 (0.93)	55 (-0.67)	84 (-0.25)
Wheat	10.4 (-1.20)	5.4 (-1.28)	42 (0.09)	19 (0.00)	45 (0.30)	73 (0.11)
Fruits and Nuts (22 outputs)	**9.4 (1.41)**	**5.0 (1.33)**	**43 (-0.08)**	**11 (-1.10)**	**79 (0.39)**	**90 (0.21)**
Oranges	1.8 (0.11)	1.0 (0.03)	4 (-0.39)	3 (-0.71)	100 (0.01)	100 (0.00)
Grapes	1.7 (2.80)	0.9 (2.72)	14 (-0.63)	5 (-0.98)	96 (0.07)	100 (0.02)
Apples, all varieties	1.4 (0.92)	0.7 (0.84)	35 (-0.16)	17 (-1.40)	64 (0.71)	82 (0.28)

Table 8.4. Continued

Output	Value (billions 2000 $) (1)	Share of Total Value (%) (2)	Number of States with: Value > 0 (3)	Value > 1% (4)	Share (%) of Production from: Top 4 States (5)	Top 10 States (6)
	(average annual percentage change in parentheses)					
Vegetables (22 outputs)	**9.5 (1.01)**	**5.0 (0.93)**	**46 (-0.23)**	**19 (-0.53)**	**56 (0.63)**	**77 (0.35)**
Potatoes	2.8 (-0.20)	1.4 (-0.28)	40 (-0.69)	17 (-0.59)	51 (0.52)	77 (0.37)
Lettuce	1.1 (1.44)	0.6 (1.36)	13 (-2.32)	6 (-1.93)	93 (0.11)	99 (0.02)
Tomatoes, fresh	1.0 (1.54)	0.5 (1.46)	23 (-0.98)	13 (-0.14)	78 (0.09)	91 (0.11)
Nursery and Greenhouse	**6.9 (3.14)**	**3.7 (3.06)**	**48 (-0.04)**	**24 (0.00)**	**45 (0.47)**	**68 (0.15)**

Source: Alston et al. 2010 using InSTePP data.

included (in parentheses). Column 1 shows the average annual value of production of each aggregated output category and the three individual outputs in that category with the highest value of production, measured in billions of real 2000 dollars (i.e., nominal prices adjusted for inflation by dividing the nominal values by the implicit price deflator for gross domestic product; in short, the implicit GDP deflator). Column 2 shows the same value of production, expressed as a percentage of the national total. For instance, field crops accounted for approximately $72 billion in annual production value, averaged across the time period. On average from 1949 to 2006, field crops accounted for 37.2% and livestock outputs accounted for 48.0% of the U.S. value of production of all agricultural outputs included in the dataset. Fruits and nuts accounted for 5.0% of U.S. production value, and vegetables also accounted for about 5.0%.

The next two columns in Table 8.4 indicate the degree to which the production of each output was spread among states. Column 3 indicates the average number of states with some measured production of the output indicated. Column 4 indicates the number of states that accounted for more than 1% of the total value of production, on average. For instance, on average, 46 states reported some production of field crops, but only 28 states contributed more than 1% of the total U.S. value of production of field crops. The bulk of the production value was concentrated in about 30 states for both field crops and livestock. Production of fruits, nuts, and vegetables was much more spatially concentrated. Only 11 states individually contributed more than 1% of the value of production of fruits and nuts, and only 18 states individually contributed more than 1% to the value of production of vegetables. The last two columns of Table 8.4 provide another measure of the degree of concentration of production of a particular output among states—the average share of production value from the 4 (column 5) and 10 (column 6) states with the greatest production of that output. For instance, the top four states accounted for only 33% of the total value of field crop production (on average), whereas the top four states accounted for 79% of total fruit and nut production. While some of the aggregate measures reveal interesting differences (e.g., between livestock versus fruits and nuts), the aggregate measures mask variation among outputs. Data presented in Table 8.4 also indicate the relative importance and concentration of individual outputs within aggregates. For instance, while the top four states accounted for only 27% of total U.S. production of livestock, production of broilers and hogs was much more concentrated, with the top four states accounting for roughly half of the value of production of these two commodities.

Figure 8.4 shows how the value shares of the output categories changed after 1949. The value share of field crops jumped to more than 40% in the 1970s and 1980s when commodity prices were high. Aside from that period

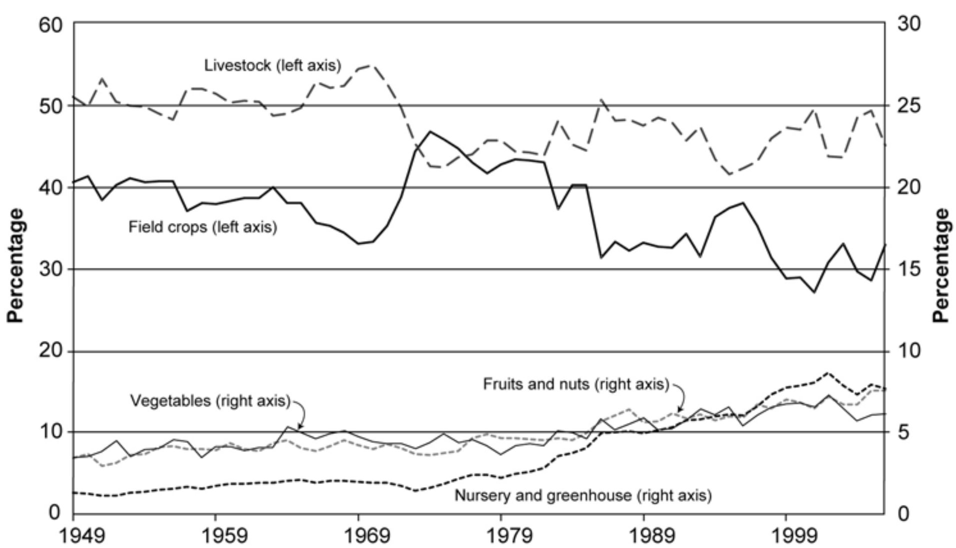


Figure 8.4. Value shares of output categories, 1949-2006
Source: Alston et al. 2010, based on InSTePP data.

of time, the share of agricultural output value coming from field crops fluctuated around a generally downward trend, declining from approximately 40% of the total value of agricultural output in this data set in 1949 to around 30% in more recent years. The value of livestock as a share of agricultural production also trended down, declining from about half the value of production in the 1950s to around 45% in more recent years. Mirroring the declining shares of output value contributed by livestock and field crops was an increase in the value shares for fruits and nuts, vegetables, and greenhouse and nursery products. The value shares for vegetables and the fruit and nut group followed very similar paths over the latter half of the twentieth century—they both increased from about 3.5% in 1949 to 6.5% in recent years. The value share of greenhouse and nursery products increased much more quickly, from less than 1.5% in 1949 to around 8% in 2006.

5. U.S. AGRICULTURAL PRODUCTIVITY

In this section, we present an analysis of national, regional, and state-specific measures of input use, outputs, and MFP in which we pay some graphical and statistical attention to the hypothesis that productivity growth has recently slowed. The results of this analysis suggest a general slowdown of productivity growth toward the end of the period. At the end of the section we briefly consider other measures of productivity (partial factor productivities including crop yields) as supplementary evidence relative to the slowdown conjecture.

A number of statistical databases of inputs, outputs, and productivity in U.S. agriculture have been constructed over the past half century or so, no two of which used exactly the same methods. Significant refinements in methods have increased the accuracy of measures of inputs and outputs in U.S. agriculture. Some of these improvements include refinements to indexing procedures, the incorporation of quality changes, utilization adjustments, and the use of disaggregated data. Table 8.5 lists studies that reported estimates of U.S. agricultural productivity growth, classified in the table by whether index number (or growth accounting) approaches or parametric approaches were used to estimate productivity.

Across all of the 32 studies listed in the table, estimates of the average annual rate of productivity growth range from 0.21% to 3.50% per year; the simple average of these estimates is 1.75% per year. The wide range of the estimates of productivity growth reflects differences in time periods, databases, and estima-

Table 8.5. Estimates of multifactor productivity growth in U.S. agriculture

Study: Authors	Study: Date	Method	Sample Period	Average Annual Growth Rate (% per year)
Index number (growth accounting) approaches				
Barton and Cooper	1948	Fixed-weight	1910-1945	1.65[a]
Loomis and Barton	1961	Fixed-weight	1870-1958	0.80
Brown	1978	Tornqvist-Theil	1947-1974	1.42
Kendrick	1983	Tornqvist-Theil	1948-1979	3.50
Ball	1984 and 1985	Tornqvist-Theil	1948-1979	1.75
Capalbo and Vo	1988	Tornqvist-Theil	1948-1983	1.22
Cox and Chavas	1990	Tornqvist-Theil	1950-1983	1.89
USDA-ERS	1991	Tornqvist-Theil	1948-1989	1.58[b]
U.S. BLS	1992	Tornqvist-Theil/Fisher Ideal	1948-1990	3.06[b]
Jorgenson and Gollop	1992	Tornqvist-Theil	1947-1985	1.58
Huffman and Evenson	1993	Tornqvist-Theil	1950-1982	1.84
Craig and Pardey	1996	Tornqvist-Theil	1949-1991	1.76[c]
Ball et al.	1997	Fisher Ideal	1948-1994	1.94[c]
Ball et al.	1999	Tornqvist-Theil	1960-1990	2.00
Schimmelpfennig and Thirtle	1999	Fisher Ideal	1973-1993	3.00
McCunn and Huffman	2000	Tornqvist-Theil	1950-1982	2.00
Ball, Butault, and Nehring	2001	Fisher Ideal	1960-1996	1.94[c]
Acquaye, Alston, and Pardey	2003	Fisher Ideal	1949-1991	1.90[c]
Ball et al.	2004	Malmquist	1960-1996	1.54
USDA-ERS	2008	Fisher Ideal	1960-2004	1.70[c]
USDA-ERS	2008	Fisher Ideal	1948-2004	1.77
Alston et al.	2010	Fisher Ideal	1949-2002	1.78
Parametric approaches				
Ruttan	1956	Cobb-Douglas production	1919-1950	1.23
Ray	1982	Translog cost	1939-1977	1.80
Capalbo and Denny	1986	Translog production	1962-1978	1.41
Capalbo	1988	Translog cost	1950-1983	1.4-1.6[d]
Jorgenson	1990	Translog production	1948-1979	1.61
Dorfman and Foster	1991	Translog production	1948-1983	0.21
Luh and Stefanou	1991	Generalized Leontief Value	1948-1982	1.50

Table 8.5. Continued

Study: Authors	Study: Date	Method	Sample Period	Average Annual Growth Rate (% per year)
Karagiannis and Mergos	2000	Profit function	1948-1994	1.91 and 1.99[e]
Acquaye	2000	Translog cost	1949-1991	1.99
Andersen	2005	Translog production	1949-1991	1.31
Andersen, Alston, and Pardey	2007	Translog production	1949-2002	1.55

Source: Amended version of Alston et al. 2010 (Table 5-4).
[a]Calculated as the growth in output minus the growth in inputs from 1910 to 1945, divided by the number of periods.
[b]Calculated from multifactor productivity indexes using the regression formula, $\ln(Z) = \beta_0 + \beta_1(T)$, where Z = productivity index and T = year.
[c]Represents the average of 50 states.
[d]Data range represents a 95% confidence interval.
[e]Estimates represent an input-based and an output-based measure, respectively.

tion procedures among the listed studies. Two of the estimates of rates of productivity growth are very small and three are very large, and these are probably outliers, which we can discount for one reason or another—such as the time period to which they apply. Excluding these five outliers, the remaining 27 studies reported estimates ranging between 1.00% and 2.00% per year. Among these, the more recent estimates, especially for the more recent period, probably have greater reliability as a result of their use of better data and better methods; these estimates are typically in the range of 1.50% to 2.00% per year.

Our own estimates, using the InSTePP data, fall within the range of the more recent studies. Figure 8.5 plots the average annual growth rate of agricultural output against the corresponding annual average growth rate of agricultural input, state by state and for the nation as a whole over the 53 years, 1949-2002. Points on the 45-degree line that pass through the origin have output growing at the same rate as input and thus have zero productivity growth. All states had positive productivity growth, with input-output-growth coordinates above and to the left of the 45-degree line through the origin. Some states had both inputs and outputs growing, some had both falling, but the majority had output growing against a declining input quantity. In a few (mostly northeastern) states, productivity growth reflected a contraction in

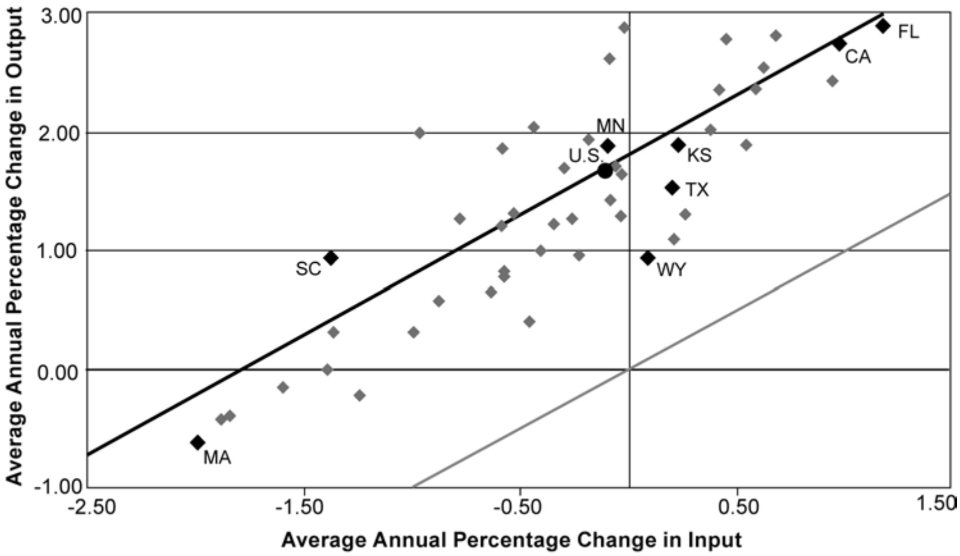


Figure 8.5. Input versus output growth rates, by state, 1949-2002
Source: Alston et al. 2010, based on InSTePP data.

input use that outweighed declining aggregate output. The 45-degree line in Figure 8.5 that passes through the observation for the national aggregate cuts the vertical axis at 1.78% per annum, the national aggregate annual average productivity growth rate. A point above that line indicates a relatively fast output growth rate for the given input growth rate (or a relatively fast reduction in inputs for a given rate of output growth), and a point below the line, the converse. In turn, we can think of the points above the line as reflecting faster-than-average productivity growth.[5]

Figure 8.6 provides a mapped representation of the input, output, and MFP growth rates and serves to further clarify the geographical structure of the rates of change in these variables during the latter half of the twentieth century. These maps reveal a tendency for higher rates of input growth as one moves westward, with states east of the Mississippi River generally exhibiting smaller rates of growth in input use than those to the west.

The pattern of MFP growth has varied widely over time. Year-to-year variations in measured productivity growth might reflect the influences of short-term, transient factors such as weather impacts or policy changes; they might also be the

[5]Appendix Table 8.A1 includes more complete details for states and regions on the average annual rates of growth of inputs, outputs, and MFP.

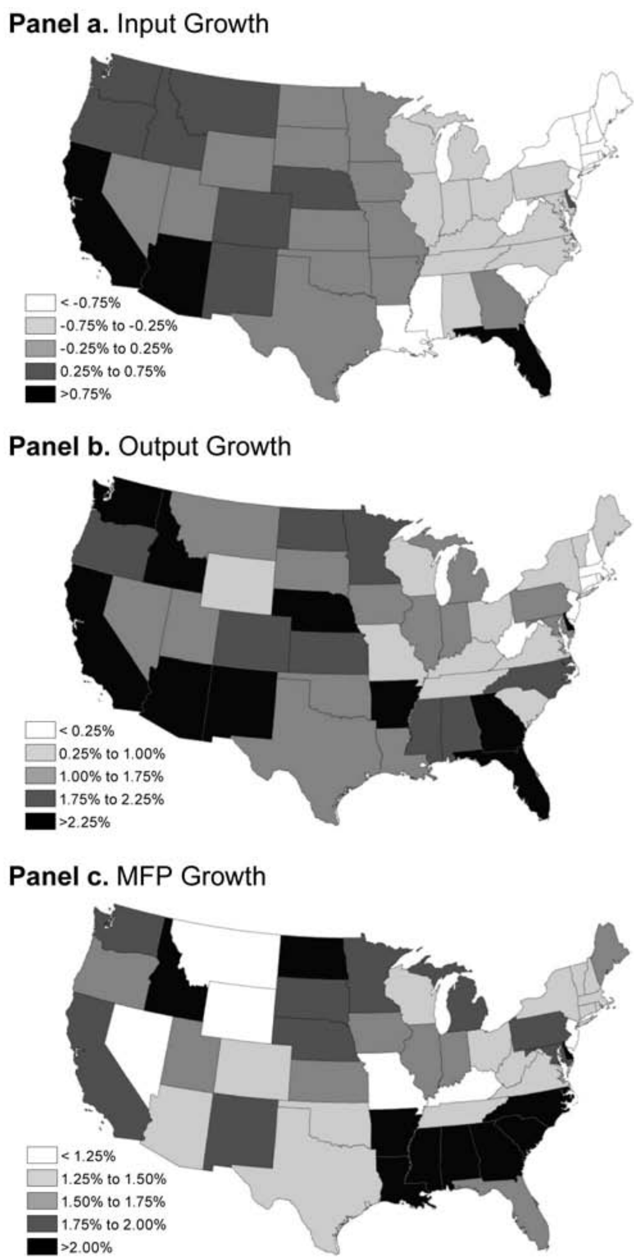


Figure 8.6. The geography of input, output, and productivity growth, 1949-2002

Source: Alston et al. 2010, based on InSTePP data.

Note: Shading denotes designated range of average annual growth rates for the period 1949 to 2002.

result of measurement errors such as those associated with variable capital utilization rates. However, secular long-term changes in patterns of productivity growth are of greater interest in the present context. In particular, accumulating evidence suggests that the rate of U.S. agricultural productivity growth may have slowed in recent years, perhaps as a reflection of a slowdown in the growth of total spending on agricultural R&D starting in the late 1970s or a reduction in the share spent on productivity-enhancing agricultural research and development (Alston, Beddow, and Pardey 2009; Alston et al. 2010). It is not a trivial matter to detect structural changes in the process of productivity growth, given the substantial year-to-year movements and spatial differences, but our richly detailed data make it possible to test for structural changes.

Evidence of a recent productivity slowdown can be seen in Figure 8.7, which shows distributions of average annual state-specific MFP growth rates over 10-year periods since 1949.[6] Each of the distributions refers to a particular period, and the data are the state-specific averages of the annual MFP growth rates for the period, a total of 48 growth rate statistics. By inspection, it can be seen that the general shape and position of the distribution of state-specific MFP growth rates seems reasonably constant across periods until the last one, 1990-2002, when it shifts substantially to the left, indicating a widespread slowdown in productivity growth. In what follows we present various measures, all of which point to a substantial slowdown of productivity growth in the period 1990-2002 compared with the prior period 1949-1990.

We calculated and compared state-specific rates of productivity growth for the period 1949-1990 and the remaining period, 1990-2002. Figure 8.8 plots state-specific MFP growth rates for these two periods. As shown in Panel b, during the period 1949-1990, MFP grew positively in all 48 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 period in only 4 states (8% of the total), with 44 states experiencing lower rates of productivity growth. U.S. 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 two periods, a paltry rate of 0.54% per year for 1990-2002 compared with 2.02% per year for 1949-1990.

[6] The periods are decades beginning in the year ending in zero except for the first period, which includes one extra year, and the last, which is extended by two years to 2002.

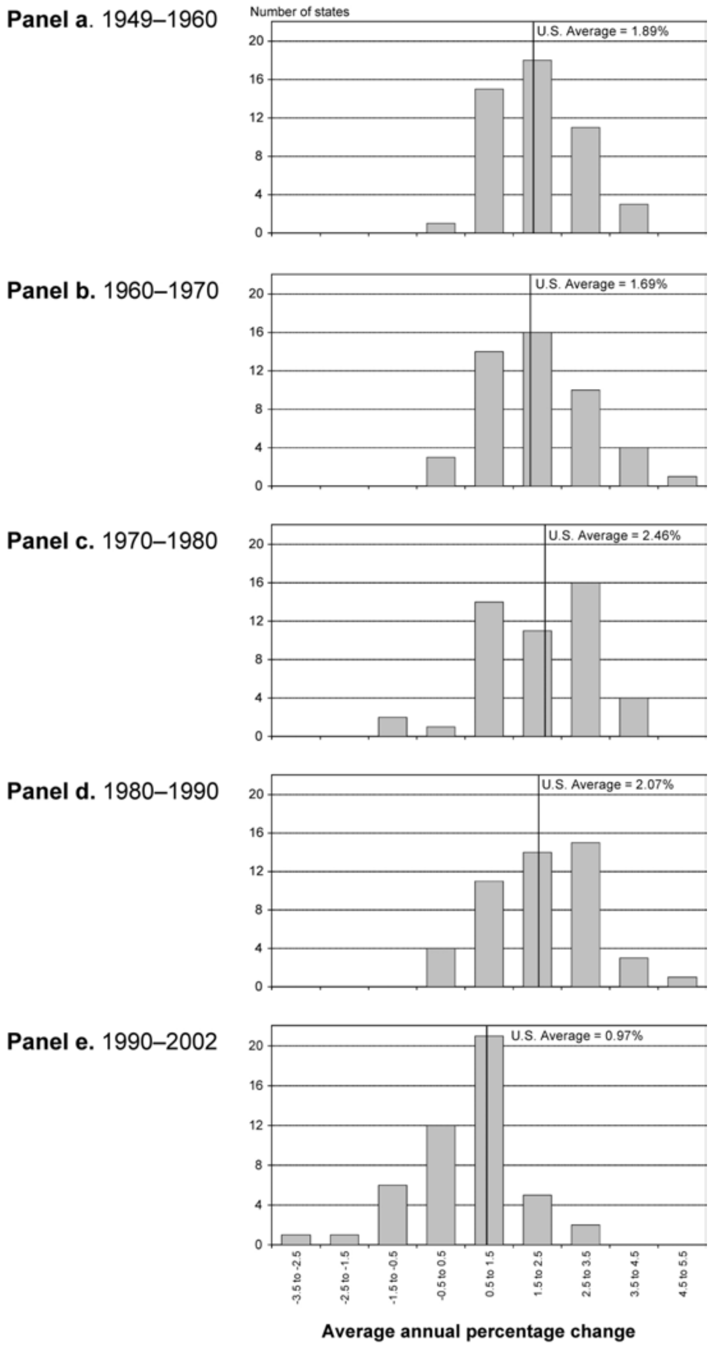
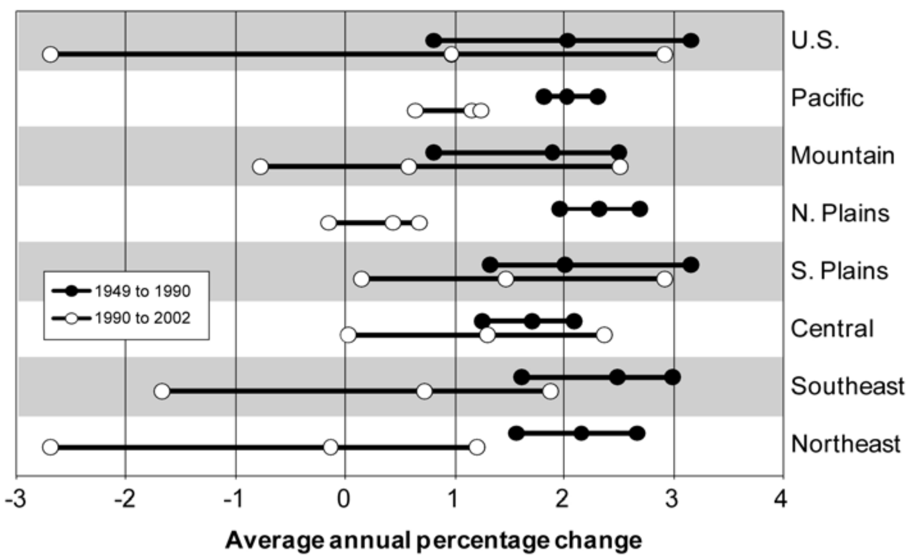


Figure 8.7. Distribution of average annual MFP growth rates across states, by decade

Source: Alston et al. 2010, based on InSTePP data.

Panel a. Linearized distributions, states grouped by region



Panel b. Full distributions, individual states

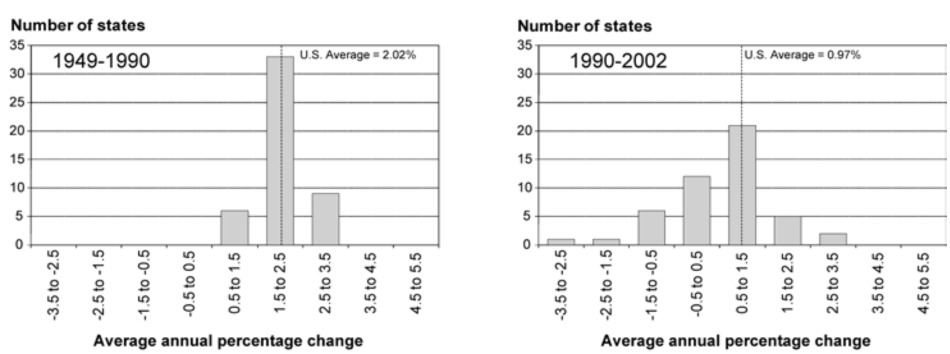


Figure 8.8. Distribution of MFP growth, 1949-1990 and 1990-2002

Source: Alston et al. 2010, based on InSTePP data.
Note: In Panel a, the three dots represent the minimum, mean, and maximum growth rates among states in the respective regions.

Figure 8.8, Panel a, plots linearized distributions (showing the minimum, maximum, and mean) of state-specific MFP growth rates grouped by regions. These linearized distributions reveal a comprehensive and significant slowing in the rate of growth in MFP in 1990-2002 compared with 1949-1990. The regional means all moved leftward (indicating a contraction in the average rate of MFP), as did the mass of most of the regional distributions. The productivity slowdown was most pronounced in the Northern Plains, Southeast, and Northeast regions.

Figure 8.9 gives a geographical perspective on the same story. Panel a depicts the state-specific average annual input, output, and MFP growth rates for 1949-1990; Panel b depicts the same information for 1990-2002. Aggregate input growth was generally higher in the 1949-1990 period compared with the 1990-2002 period (and notably so for most western states), whereas output growth generally slowed in the later period. The combination of these reinforcing input and output trends resulted in the pervasive slowdown in MFP growth that is especially evident in comparing the lowest map of Panel b with its counterpart in Panel a.

The slowdown in MFP is also reflected in measures of partial factor productivities. In Table 8.6, the average U.S. productivity of capital, labor, land, and materials grew respectively by 1.78% per year, 3.42% per year, 1.74% per year, and -0.20% per year over the period 1949-2002; the materials outlier reflects the very substantial substitution of materials inputs for other inputs, especially labor. Over the period 1990-2002, the corresponding partial productivity growth rates for capital, labor, land, and materials were respectively 0.78% per year, 1.54% per year, 1.50% per year, and 0.35% per year. A substantial slowdown is evident in the growth rates of productivity of both capital and labor. Only materials productivity grew more rapidly over 1990-2002, reflecting a slower rate of increase in the use of materials input in this period compared with the several decades immediately following the Second World War. The crop yield evidence in Table 8.7 reinforces the slowdown in growth evident in the measures of MFP and partial factor productivity. For the four major crops shown in this table, yields grew at a much slower rate over the period 1990-2006 than they did in the period 1936-1990 (and, not shown, 1949-1990).[7]

Returning to the most meaningful measures pertinent to the issue of a slowdown, we conducted more formal statistical tests for a productivity slow-

[7]See Alston, Beddow, and Pardey (2009 and Chapter 3, this volume) for more detail on the crop yield evidence for the United States and some comparable (and to some extent reinforcing) information for other countries.

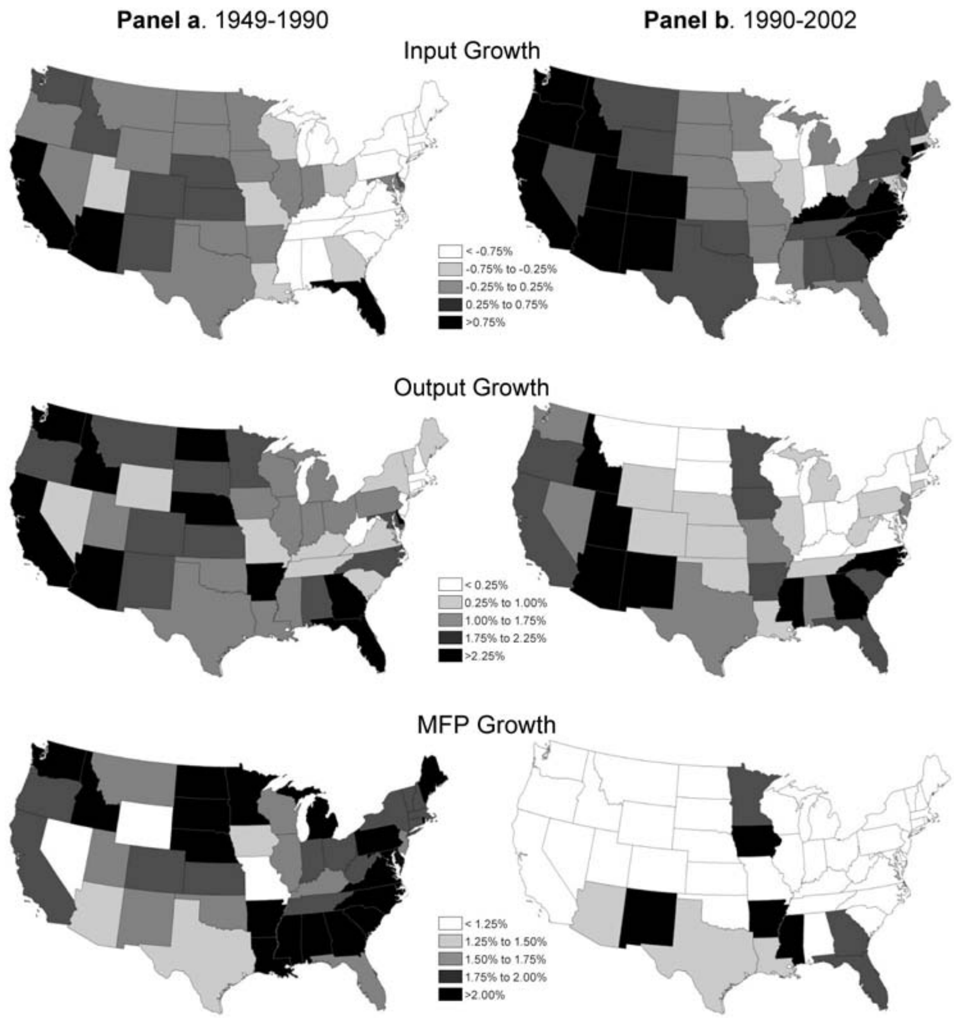


Figure 8.9. Input, output, and productivity growth rates, 1949-1990 versus 1990-2002

Source: Alston et al. 2010.
Note: Shading denotes designated range of average annual growth rates for the period 1949 to 2002.

down using the state-specific MFP data for 1949-2002, and comparing growth rates for various subperiods. Cognizant of the possibility that different measures of MFP growth may imply different findings, we tried two measures of growth combined with two methods for estimating the growth rate. The first measure of growth was linear, calculated as the annual change in the level of

Table 8.6. Annual growth rates in partial productivity measures, various subperiods

	Capital	Labor	Land	Materials
	(average annual percentage growth)			
1949-1960	1.30	4.88	1.82	-1.99
1960-1970	2.20	4.19	1.44	-1.76
1970-1980	1.61	3.71	2.14	1.60
1980-1990	3.26	3.03	1.86	0.87
1990-2002	0.78	1.54	1.50	0.35
1949-1990	2.07	3.98	1.82	-0.36
1949-2002	1.78	3.42	1.74	-0.20

Source: Alston et al. 2010.

Table 8.7. Yield growth for various commodities, 1866-2006

Measure and Period[a]	Commodity				
	Wheat	Corn	Cotton	Tobacco	Rice
Average rate of change (% per year)					
Entire period	0.9	1.3	1.4	0.7	1.6
Through 1935	0.2	-0.4	0.7	0.0	1.5
1936-2006	1.6	3.0	2.0	1.4	1.6
1936-1990	2.1	3.4	2.1	1.9	1.6
1990-2006	-0.1	1.4	1.6	-0.2	1.4
1980s	1.6	2.6	4.5	1.3	2.3
1990s	0.6	1.4	0.0	0.1	1.3
2000-06	-1.4	1.4	4.2	-0.8	1.5
Average yield gain (pounds per year)					
Entire period	11.9	49.9	4.9	9.6	58.4
Through 1935	1.5	-4.6	1.1	0.1	29.5
1936-2006	22.2	104.4	8.8	19.1	65.5
1936-1990	29.7	103.6	8.1	26.1	60.1
1990-2006	-3.0	107.1	11.3	-4.6	83.7
1980s	36.0	154.0	23.0	27.9	111.6
1990s	15.0	103.0	-0.2	2.6	75.2
2000-06	-33.0	113.9	30.3	-16.7	97.8

Source: Beddow, Pardey, and Hurley 2009.

[a]Rice values are for 1919-2006; other values are for 1866-2006.

the index. The second was proportional, calculated as the annual change in the logarithm of the index. The first method for estimating the growth rate used the simple average of the annual state-specific estimates of MFP growth. The second used a regression of each state-specific MFP index against a time trend such that the estimated coefficient on the time trend (a function of the coefficient, for proportional growth measures) provides an estimate of the average growth in the MFP index. We computed these four alternative measures for each state and for various time periods, defined in Table 8.8. Finally, we conducted paired t-tests for statistically significant differences in the state-specific growth rates before and after the split points.

The upper half of Table 8.8 refers to proportional growth in MFP, measured either as the average of year-to-year growth rates or a function of the slope coefficient from a regression of the logarithm of the index against a time-trend

Table 8.8. Statistical tests for a slowdown in MFP growth

Time Period	During Period	After Period	Difference	P-value
	(average annual percentage change in index)			
Using differences in logarithms				
1949-1960	2.04	1.59	-0.45	0.00
1949-1970	2.01	1.47	-0.54	0.00
1949-1980	2.01	1.23	-0.78	0.00
1949-1990	2.02	0.54	-1.48	0.00
Using regression of logarithms				
1949-1960	2.06	1.77	-0.29	0.06
1949-1970	1.90	1.53	-0.37	0.02
1949-1980	1.99	1.00	-0.99	0.00
1949-1990	2.06	0.57	-1.49	0.00
	(average annual change in index)			
Using differences in levels				
1949-1960	2.34	3.03	0.69	0.00
1949-1970	2.62	3.07	0.45	0.13
1949-1980	2.87	2.93	0.06	0.82
1949-1990	3.28	1.56	-1.72	0.00
Using regression of levels				
1949-1960	2.33	3.45	1.12	0.00
1949-1970	2.46	3.29	0.83	0.01
1949-1980	2.86	2.43	-0.43	0.16
1949-1990	3.36	1.54	-1.83	0.00

Source: Alston et al. 2010.

variable. In every case, with either measure, the tests indicate a substantial and statistically significant (at the 10% level of significance in every case, and in most cases at a level of significance well under 1%) slowing of productivity growth for any period that includes the years 1990-2002 compared with any prior period. The slowdown is most pronounced for 1990-2002 compared with 1949-1990. An absolute increase in productivity is necessary but not sufficient to sustain proportional productivity growth. The lower half of Table 8.8 indicates a slowdown in absolute productivity growth in 1990-2002 compared with 1949-1990, but the evidence is more mixed for the earlier breakpoints.

6. CONCLUSION

U.S. agricultural production changed remarkably over the past 100 years. Agricultural output and productivity grew very rapidly in the post–World War II era. Those 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. However, mounting evidence indicates that the structural slowdown in the growth rate of U.S. agricultural productivity has been substantial, sustained, and systematic. Over the most recent 10 to 20 years of our data, the annual average rate of productivity growth was half the rate that had been sustained for much of the twentieth century. Compounding over decades, the difference will have serious implications. Unless other countries with competing agricultural production experience comparable slowdowns in agricultural productivity growth, the United States will suffer a widening competitiveness gap. On the other hand, if other countries do experience comparable slowdowns in agricultural productivity growth, the consequences will be felt in a widening gap of a different sort: between growth in global supply and growth in global demand for agricultural products.

APPENDIX A: STATE AND REGIONAL GROWTH OF INPUTS, OUTPUTS, AND MFP

Table 8.A1. State- and region-specific input, output and productivity growth, 1949-2002

	Growth, 1949-2002			MFP Growth				
	Input	Output	MFP	1949-1960	1960-1970	1970-1980	1980-1990	1990-2002
	(average annual percentage change)							
United States	**-0.11**	**1.68**	**1.78**	**1.89**	**1.69**	**2.46**	**2.07**	**0.97**
Pacific	**0.82**	**2.64**	**1.82**	**1.60**	**2.31**	**2.99**	**1.21**	**1.15**
California	0.97	2.74	1.77	1.66	2.22	2.84	1.01	1.24
Oregon	0.37	2.03	1.65	1.41	1.90	2.68	1.28	1.13
Washington	0.62	2.55	1.93	0.71	2.76	3.79	2.11	0.64
Mountain	**0.45**	**2.04**	**1.59**	**1.73**	**2.10**	**1.89**	**1.85**	**0.57**
Arizona	0.94	2.43	1.48	1.45	0.70	3.17	0.67	1.44
Colorado	0.54	1.90	1.35	1.54	1.98	1.81	2.31	-0.53
Idaho	0.68	2.82	2.14	1.70	2.92	2.64	2.80	0.94
Montana	0.26	1.31	1.04	1.81	2.00	0.94	1.54	-0.78
Nevada	0.21	1.09	0.88	0.89	0.94	1.48	-0.14	1.16
New Mexico	0.59	2.36	1.77	1.05	2.15	1.45	1.62	2.51
Utah	-0.08	1.43	1.51	1.89	2.38	0.06	2.61	0.72
Wyoming	0.09	0.93	0.84	2.06	0.71	1.21	0.21	0.04
Northern Plains	**0.16**	**2.05**	**1.89**	**2.84**	**1.22**	**1.76**	**3.39**	**0.43**
Kansas	0.23	1.90	1.67	3.48	0.44	1.22	2.54	0.67
Nebraska	0.42	2.35	1.94	2.41	1.41	2.06	3.42	0.60
North Dakota	-0.18	1.94	2.12	2.19	1.63	2.00	4.99	0.19
South Dakota	-0.07	1.70	1.77	2.96	1.59	1.33	3.39	-0.15
Southern Plains	**-0.12**	**1.76**	**1.88**	**1.53**	**2.06**	**1.99**	**2.49**	**1.47**
Arkansas	-0.02	2.87	2.89	3.12	3.59	2.81	3.12	2.00
Louisiana	-0.78	1.26	2.04	1.05	4.32	1.96	1.67	1.42
Mississippi	-0.97	1.99	2.95	3.86	3.90	1.42	2.57	2.93
Oklahoma	-0.04	1.29	1.33	2.01	0.33	2.90	1.42	0.15
Texas	0.20	1.53	1.32	0.39	1.01	1.39	2.61	1.32
Central	**-0.27**	**1.34**	**1.61**	**1.46**	**0.97**	**2.74**	**1.66**	**1.30**
Illinois	-0.27	1.27	1.54	1.47	0.08	2.61	2.61	1.03
Indiana	-0.34	1.21	1.56	1.48	0.55	2.87	2.13	0.89

Table 8.A1. Continued

	Growth, 1949-2002			MFP Growth				
	Input	**Output**	**MFP**	**1949-1960**	**1960-1970**	**1970-1980**	**1980-1990**	**1990-2002**
	(average annual percentage change)							
Iowa	-0.03	1.65	1.68	1.10	0.97	2.80	1.10	2.37
Michigan	-0.59	1.20	1.79	0.94	2.34	3.69	1.50	0.76
Minnesota	-0.10	1.89	1.99	1.88	1.41	2.67	2.09	1.91
Missouri	-0.23	0.96	1.19	1.64	0.58	1.96	0.74	1.02
Ohio	-0.58	0.83	1.40	1.22	0.92	3.57	1.57	0.02
Wisconsin	-0.40	1.00	1.40	1.49	1.37	1.97	1.46	0.82
Southeast	**-0.41**	**1.68**	**2.09**	**2.33**	**2.39**	**2.96**	**2.30**	**0.72**
Alabama	-0.59	1.86	2.45	3.37	2.29	2.58	3.38	0.85
Florida	1.18	2.90	1.72	0.97	2.12	4.07	-0.38	1.87
Georgia	-0.09	2.63	2.71	4.02	2.65	2.17	2.99	1.80
Kentucky	-0.46	0.41	0.87	1.32	1.55	1.95	1.66	-1.69
North Carolina	-0.44	2.04	2.48	2.34	2.67	3.14	3.88	0.74
South Carolina	-1.38	0.94	2.32	1.82	3.10	3.03	3.04	0.93
Tennessee	-0.63	0.65	1.28	1.55	1.26	3.17	1.05	-0.32
Virginia	-0.58	0.78	1.36	1.33	1.51	1.86	3.54	-0.97
West Virginia	-1.60	-0.15	1.44	1.95	0.83	2.68	2.44	-0.38
Northeast	**-0.84**	**0.80**	**1.64**	**2.34**	**2.36**	**1.72**	**2.18**	**-0.14**
Connecticut	-1.39	0.00	1.39	2.54	2.09	0.77	2.14	-0.36
Delaware	0.45	2.78	2.33	3.83	2.66	1.02	3.02	1.20
Maine	-1.37	0.31	1.67	3.47	4.73	-1.38	2.04	-0.28
Maryland	-0.30	1.69	1.99	2.71	2.82	1.30	2.69	0.62
Massachusetts	-1.99	-0.62	1.37	2.97	3.18	1.99	-0.41	-0.62
New Hampshire	-1.88	-0.42	1.46	3.31	3.66	-0.54	0.91	0.06
New Jersey	-1.25	-0.22	1.03	2.22	1.00	0.89	2.07	-0.81
New York	-0.99	0.31	1.30	1.81	1.92	1.88	1.76	-0.54
Pennsylvania	-0.53	1.30	1.83	2.04	2.20	2.80	2.53	-0.05
Rhode Island	-1.84	-0.39	1.45	2.68	2.79	1.01	4.20	-2.70
Vermont	-0.87	0.57	1.44	2.71	3.08	0.62	1.04	-0.07

Source: Alston et al. 2010.

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CHAPTER 9

Agricultural Productivity in China

Songqing Jin, Jikun Huang, and Scott Rozelle

1. INTRODUCTION

Few scholars would question the positive and substantive role that agriculture played in substantially expanding the supply of food and fiber and spurring the broader economic development of the Chinese economy, beginning with the modern reforms of the agricultural sector that were first launched in the late 1970s (Rozelle, Huang, and Otsuka 2005). Based in part on the incentives embodied in the Household Responsibility System, farm output and productivity grew by 5% to 10% per annum between 1978 and 1985 (McMillan Whalley, and Zhu 1989; Lin 1992). Huang and Rozelle (1996) and Fan and Pardey (1997) showed that the output-promoting effects of these improved incentives were enhanced by new technologies. Input use also rose as farmers had greater access to fertilizer and other farm inputs (Stone 1988) and improved water control, especially because of the emergence of groundwater privatization (Nickum 1998; Wang, Huang, and Rozelle 2005).

During the mid-1990s, at a time when China's rapid growth was transforming people's livelihoods, another debate arose concerning China's ability to feed itself over the medium to long run. Brown (1994), among others, pointed out that the intensity of input use was already high in China and that

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continued growth in agricultural output would increasingly rely on growth in total factor productivity (TFP). The pessimists (e.g., Wen 1993) suggested that TFP had stopped growing and that the output of China's farming sector might soon stagnate. In response, several efforts (e.g., Fan 1997; Jin et al. 2002) used more rigorous methods and showed that while inputs in aggregate had indeed stopped growing (as labor shifted off the farm and sown area stagnated), output continued to grow, resulting in positive TFP growth at a respectable rate of around 2% per year. Although there were many challenges facing the Chinese agricultural economy, investments in agricultural research and development (R&D) over several decades contributed to a stream of new technologies (including new seed varieties) that was continuing to fuel TFP growth as the decade of the 1990s came to an end given the long lags linking R&D spending to productivity growth.

Somewhat surprisingly perhaps, little effort has been devoted to assessing the productivity performance of Chinese agriculture in recent years. The most recent relevant studies only covered the data up to the mid-1990s (e.g., up to 1995 in Jin et al. 2002; and up to 1997 by Fan and Zhang 2002). The task of meaningfully measuring China's agricultural productivity performance is especially challenging. There have been (and continue to be) tremendous changes within the sector, particularly, rapidly evolving institutional structures, that make it difficult to gauge agricultural productivity developments within China. For example, research spending has waxed and waned (Hu et al. 2007), policies to encourage the import of foreign technologies have been unevenly applied (Pray, Rozelle, and Huang 1997), and structural adjustment policies have also triggered wrenching changes in the sector (Rosen, Huang, and Rozelle 2004). In addition, horticulture and livestock production has boomed, while the output of other crops, such as rice, wheat, and soybeans, has stagnated or fallen (CNBS 2005). At a time when China's millions of producers are faced with complex decisions, the extension system is crumbling and farmer professional associations remain in their infancy (Huang, Hu, and Rozelle 2003). In short, there are just as many reasons to be pessimistic about the productivity trends in agriculture as to be optimistic.

The overarching goal of this chapter is to provide a better understanding of input, output, and productivity trends in China's agricultural sector during the reform era that began in the late 1970s, with an emphasis on the period 1990-2004. To do so, we pursue three specific objectives. First, relying on the

National Cost of Production Data Set—China's most complete set of farm input and output data—we chart the input and output trends for 23 of China's main farm commodities. Second, using a stochastic production frontier function approach we estimate the rate of change in TFP for each commodity. Finally, we decompose the changes in TFP into two components: changes in efficiency and changes in technical change.

To keep the assessment manageable, we limit the scope of our analysis to the major staple grains and oilseeds, cotton, several vegetable and fruit crops, and most of the major livestock commodities. In total, the commodities we include accounted for more than 65% of China's gross value of agricultural output in 2005 (CNBS 2006). Our analysis of TFP developments omits a consideration of several major commodities, including aquaculture, sugar, edible oils beyond soybeans, and many fruits, vegetables, and more minor livestock commodities. In addition, we measure productivity performance on a commodity-by-commodity basis. As deBrauw, Huang, and Rozelle (2004) and Lin (1992) suggested, if farm specialization is occurring in China, as more recent work by Rozelle et al. (2007) confirmed, then we would expect allocative efficiency gains. In this case our evaluation approach will underestimate the rate of growth in farm productivity within China since we will not pick up productivity gains that would arise from producers shifting crops. In our presentation of our results, we also ignore regional differences in productivity, even though our analysis was done at a provincial level and then aggregated to form the national totals reported here.

In the following sections we first present a brief review of our methodology. Then we discuss the data, followed by a brief review of recent changes in Chinese agriculture and how these might be expected to affect TFP. Understanding these trends will be helpful in interpreting the results. TFP growth results and their decomposition are then presented for the 23 commodities.

2. METHODOLOGY

Indexed, number-based studies of productivity growth in agriculture compute productivity as a residual after accounting for input growth. If an economy is (or its producers are) operating efficiently, the growth in productivity can be interpreted as the contribution of technical progress. However, this interpretation is valid only if firms are technically efficient and realizing the full potential of the technology. The fact is that for various reasons firms do not operate efficiently. When this is so, measured changes in TFP will reflect both technological innovation and changes in efficiency. Therefore, technical progress may not be the only source of total productivity growth, and it will be possible to increase productivity through improving the method of application of the given technology—that is, by improving technical efficiency.

To study production efficiency, the stochastic frontier production function approach introduced by Aigner, Lovell, and Schmidt (1977) and Meeusen and van den Broeck (1977) has been widely deployed, with more recent extensions to this basic approach described by Battese and Coelli (1995). Stochastic production function analysis allows for the possibility that firms may exhibit technical inefficiency, in so much as firms may operate below an envelope or efficient frontier. A host of theoretical and empirical studies of production efficiency/inefficiency have used stochastic frontier production approaches (see, e.g., Coelli, Rao, and Battese 1998, and Kumbhakar and Lovell 2000 for a review of the various approaches that have been used).

As panel data sets (i.e., a combination of time-series and cross-section data) permit a richer specification of technical change, and obviously contain more information about a particular firm than a single cross-section of firm data, recent developments in measuring changes in productive efficiency over time have focused on the use of panel data (Kumbhakar, Heshmati, and Hjalmarsson 1999, and Henderson 2003). Panel data also enable some of the strong assumptions related to efficiency measurement in a cross-sectional framework to be relaxed (Schmidt and Sickles 1984), and so we adopt a panel data approach to measuring and decomposing TFP growth for the 23 commodities included in our study.

Formerly (and following Kumbhakar 2000), a stochastic frontier production function for panel data can be expressed as

$$y_{it} = f(x_{it}, t)\exp(v_{it} - u_{it}) \tag{1}$$

where y_{it} is the output of the ith firm (i=1,2,$\cdots$,N) in period t (t=1,2,$\cdots$,T); $f(\cdot)$ is the production technology; $\mathbf{x}$ is a vector of J inputs; t is the time trend variable; v_{it} is assumed to be an independently and identically distributed random variable $N(0, \sigma_v^2)$, independently distributed of the u_{it}; and u_{it} is a non-negative random variable and output-oriented technical inefficiency term. There are several specifications that make the technical inefficiency term u_{it} time-varying, but most of them have not explicitly formulated a model for these technical inefficiency effects in terms of appropriate explanatory variables.[1] Battese and Coelli (1995) proposed a specification for the technical inefficiency effect in the stochastic frontier production function as

$$u_{it} = z_{it}\delta + w_{it} \tag{2}$$

where the random variable w_{it} is defined by the truncation of the normal distribution with zero mean and variance σ^2, such that the point of truncation is $-z_{it}\delta$, that is, $w_{it} \geq -z_{it}\delta$. As a result, u_{it} is obtained by truncation at zero of the normal distribution with mean $z_{it}\delta$ and variance σ^2. The conventional assumption that the u_{it}s and v_{it}s are independently distributed for all i=1,2,$\cdots$,N and t=1,2,$\cdots$,T is obviously a simplifying but restrictive condition.

Technical inefficiency, u_{it}, measures the proportion by which actual output, y_{it}, falls short of maximum possible output or frontier output, $f(x,t)$. Therefore technical efficiency (TE) can be defined as

$$TE_{it} = y_{it} / f(x_{it},t) = \exp(-u_{it}) \leq 1\,. \tag{3}$$

Time is included as a regressor in the frontier production function and used to capture trends in productivity change—popularly known as exogenous technical change—and is measured by the log derivative of the stochastic frontier production function with respect to time (Kumbhakar 2000). That is, technical change (TC) is defined as

$$TC_{it} = \frac{\partial \ln f(x_{it},t)}{\partial t}\,. \tag{4}$$

Productivity change can be measured by the change in TFP and is defined as

$$\dot{TFP}_{it} = \dot{y}_{it} - \sum\nolimits_{J} S_{jit}\,\dot{x}_{jit} \tag{5}$$

where S_{jit} is the cost-share of the jth input for the ith firm at time t. Kumbhakar has shown that the overall productivity change can be decomposed by differentiating equation (1) totally and using the definition of TFP change in equation (5). This results in a decomposition of the TFP change into four components: a scale effect, pure technical change, technical efficiency change, and an input price allocative effect.

[1]See Kumbhakar and Lovell (2000, Chap. 7), and Cuesta (2000) for a review of recent approaches to the incorporation of exogenous influences on technical inefficiency.

3. DATA AND METHODOLOGY FOR CREATING TFP MEASURES

Historically, estimates of China's cropping TFP have been controversial, arriving at significantly different conclusions.[2] Poor data and ad hoc input weights that are constant over time may account for the debates and uncertainty over pre- and post-reform productivity studies (Fan and Zhang 2002). Researchers gleaned data from a variety of sources; they warn readers of the poor or questionable quality of many of the input and output series (Stone and Rozelle 1995).

In this chapter, we overcome some of the shortcomings of the earlier studies by utilizing a set of data that has been collected in a more-or-less consistent fashion for the past 25 years by the State Price Bureau. Using a sampling framework that includes more than 20,000 households, enumerators collected data on the farm-level costs of production of all of China's major crops. The data set includes information on the quantities used and total expenditures of all major inputs, as well as expenditures on a large number of miscellaneous items for farms in all provinces spanning the period 1985 to 2004. Farmers also report output produced and the total revenues earned from each crop. Provincial surveys by the same statistical unit also report unit costs for labor that reflect the opportunity cost of the daily wage forgone by crop farmers. During the last several years, these data have been published by the State Development and Planning Commission ("The Compiled Materials of Costs and Profits of Agricultural Products of China," SPB, 1988-2004). The same data have been used in analyses of China's agricultural supply and input demand (see studies by Huang and Rozelle 1996; Huang, Rosegrant, and Rozelle 1995; World Bank 1997; and Jin et al. 2002).

To facilitate comparisons with previous studies that mostly examined grain crops, we examine TFP developments for rice, wheat, and corn in addition to a wide array of other important crops in China. Because production characteristics of the major types of rice vary markedly, we provide separate TFP analyses for early and late indica varieties (or long grain rice) and for japonica varieties (short/medium grain rice). We also examine productivity trends for China's largest non-grain staple crops, namely, soybeans and cotton.

The rise of China as a major producer (and exporter) of horticultural crops, plus its evident comparative advantage in producing labor-intensive farm commodities led us to also include four vegetables (capsicum, eggplant, cucumbers,

[2]For example, in Stone and Rozelle (1995), studies by Tang and by Lin and Weins are reviewed. The different studies have arrived at strikingly different conclusions. Tang argued that productivity was stagnant; Lin and Weins demonstrated that productivity growth was positive.

and tomatoes) and two fruit crops (mandarins and oranges). Because cucumbers and tomatoes are grown in large quantities, both as a field and a greenhouse crop, we also examine TFP trends separately for these two crops.

The increasing importance of livestock products in China and the prospect for ever-increasing demand for these products motivated the inclusion of hogs, egg, beef cattle, and dairy in this study. Because of the substantial differences in the technologies used by China's backyard producers versus specialized households versus commercial sectors, we segregate our sample of farm households to enable TFP trends to be measured for these different modes of production. In particular, we formed separate TFP measures for hog production stratified by backyard producers, specialized households (those raising relatively large numbers of hogs), and commercial hog producers (called state- and collective-owned farms). We also stratified egg production into specialized household and commercial producers. Absent information on the different modes of beef cattle production, the TFP analysis for this commodity deals with beef cattle in aggregate. Finally, we examined TFP trends for two types of dairy producers: specialized household milk producers and commercial farms.

Data for the livestock sector were particularly problematic, requiring that we make a number of assumptions (e.g., about the relatively higher quality of the consumption statistics compared to production statistics) and resort to the use of external pieces of information (e.g., from China's 1996 Census of Agriculture) to construct a data set that facilitated an analysis at the province level. These general adjustments are described in detail in Appendix A. Some specific adjustments were also needed for the dairy sector, and these are described in Appendix B and in Ma et al. (2006).

Notwithstanding the considerable merits of this data set, it nonetheless has several important limitations. First, given China's "grain-first" emphasis in the 1980s, the coverage of non-grain crops is extremely spotty during this period. This limitation meant that TFP estimates for the 1980s could only be formed for rice, wheat, corn, soybeans, and cotton. For these five commodities and the remaining 18 commodities, we also report TFP estimates for the period 1990-2004 (or in some cases to 2003). Given that some of the required data for several commodities were unavailable for some provinces, we had no option in a number of instances but to use unbalanced panel estimation methods. The data coverage (i.e., the number of provinces and the number of years) for each commodity is detailed in Appendix C. Despite these limitations the commodities included in our analysis accounted for more than 62% of total gross agricultural value (excluding forestry and fishery) during the 2000-2005 period.

4. ECONOMIC FACTORS, STRUCTURAL CHANGE, AND PRODUCTIVITY

There are three major influences likely to affect the rate of change and the sources of those changes for our commodity-specific estimates of productivity growth: (a) investments in the domestic agricultural R&D system and the international trade and transfer of new ideas and new technologies, (b) the performance of the agricultural extension system, and (c) other economic factors that affect the incentives of farmers to choose different crop mixes and modes of production (e.g., backyard versus commercial operations) and different technologies (e.g., greenhouse versus field operations).

4.1. Technology Development

After the 1960s, China's research institutions grew rapidly, from almost nothing in the 1950s to a system that now produces a steady stream of new varieties and other technologies. China's farmers were using domestically produced semi-dwarf rice varieties several years before the release and uptake of such green revolution varieties elsewhere in the world (Huang and Rozelle 1996). Yields of Chinese-bred conventional rice, wheat, and sweet potato varieties were comparable to yields being achieved in some of the most productive agricultural economics in the world (Stone 1988).

Agricultural research and plant breeding in China are almost completely funded and conducted by the government (Huang, Hu, and Rozelle 2003). Reflecting an urban bias in most food policies, most crop breeding programs continued to emphasize small grains (specifically rice and wheat) until the 1990s. For national food security considerations, high yields were a dominant target for Chinese research and remain so, although in more recent years quality improvement has also become a target in the nation's development plans. As demand for agricultural output continues to diversify and average per capita incomes continue to grow, increasing attention has also been given to horticultural and livestock breeding.

A nationwide reform in research was launched in the mid-1980s (Pray, Rozelle, and Huang 1997; Fan and Pardey 1992). The reforms sought to spur research productivity by shifting funds from institutional support to competitive grants, supporting research deemed useful for economic development, and by encouraging applied research institutes to support themselves by selling the technology they produce. In addition, beginning in the late 1980s and early 1990s, a more open approach to the importation of new horticultural seeds, genetics for improving the nation's livestock inventories (Rae et al. 2006), and new dairy technologies (Ma et al. 2006) were instigated.

After waning for more than a decade—between the early 1980s and mid-1990s—investment in agricultural R&D finally began to rise (Pray, Rozelle, and Huang 1997). Funding was substantially increased for plant biotechnology, although only Bt cotton has been commercialized to any significant extent (Huang et al. 2002). Government investment in agricultural R&D increased by 5.5% annually between 1995 and 2000, and by more than 15% annually after 2000 (Hu et al. 2007).

4.2. Extension System

While the pace of spending on agricultural R&D has picked up considerably in the past decade or so and the efforts to restructure and reform the institutions engaged in R&D have met with some success, the country's extension system has seen few if any major successes of late. The extension system in China was once seen as an effective agency in moving technology from the experiment station to the farm and for giving cogent advice for dealing with pests and diseases and other production-limiting problems. A publicly funded system, extension had agents at the county and township levels, supported by ties to provincial research agencies that maintained experiment stations in almost every prefecture. Most villages (or in the pre-reform socialist era, most communes) appointed one or more representatives to be liaisons between the farmers in that village and the extension system.

After the mid-1980s, however, fiscal pressures at all levels of government induced local officials to commercialize the extension system. In most localities this meant partially privatizing the position of extension agents (Park and Rozelle 1998). In exchange for working part of the time doing traditional extension activities, extension agents were allowed to go into business, most often selling seeds, fertilizer, and pesticides. The profits from their business activities were supposed to cross-subsidize their extension activities. Many extension agents found their salaries reduced by half or more as a consequence of these changes, and in many areas, payments from the public purse eventually ceased (but often with no commensurate change in their public extension responsibilities).

As might be expected, these arrangements meant that extension agents eventually spent most or all of their time on their income-earning activities, and so the extension system almost completely collapsed. Surveys found that most cropping farmers rarely, if ever, saw extension agents. Other studies have documented extension agents "overselling" pesticides and providing farmers with inaccurate information when the emergence of new technologies (e.g., Bt cotton seeds) conflicted with their business practices, specifically the sale of pesticides (Huang, Hu, and Rozelle 2003). In fact, Jin et al. (2002) found that the greater the extension effort, the lower the productivity. A recent survey showed that dairy, livestock, and horticulture farmers received little if any support from the formal extension system (which is still staffed largely with agronomists trained during the grain-first years of China's agricultural policy).

4.3. Other Factors

There are other economic factors affecting the nation's agricultural productivity. Not least of these is the fact that China's agricultural economy has been steadily transforming itself 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. For example, between 1978 and 1984, grain production generally increased by 4.7% per year and production rose for each of the major grains, specifically rice, wheat, and corn. However, after the mid-1990s, with the exception of corn, which is now almost exclusively used for feed, the area sown to rice and wheat has fallen, as has the production of these two staple crops.. Although this may concern old-time grain fundamentalists inside China, in fact, 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 have shifted the pattern of consumption away from staple food grains.

Like the grain sector, cash crop production in general and production of specific crops such as cotton, edible oils, vegetables, and fruits also grew rapidly in the early reform period compared with the 1970s. Unlike the grain sector (with the exception of land-intensive staples such as cotton), the growth of the non-grain sector continued throughout the reform era. For example, between 1990 and 2004, the increase in vegetable production capacity has been so rapid that China has been adding the equivalent of the production capacity of California every two years. Moreover, the share of cultivated area in China dedicated to fruit orchards (over 5% in 2000) is more than double the share of the nextclosest major agricultural producer (e.g., the share of fruit orchards in sown area is lower in the United States, the European Union, Japan, and India).

The growth in livestock and fisheries output outpaced the growth in output from the cropping sector in total and in most subcategories. Livestock production increased by 9.1% per year in the early reform period and has continued to grow at between 4.5% and 8.8% per year since 1985. Fisheries production has been the fastest-growing component of agriculture, increasing by more than 10% per year during the 1985-2000 period. Today, more than 70% of the world's freshwater aquaculture is produced in China. These differential growth rates are bringing about substantial structural shifts in the Chinese agricultural economy. After remaining fairly static during the socialist era, the cropping share of Chinese agriculture gross domestic product fell from 76% in 1980 to 51% in 2005. Over this same time period, the combined livestock and fisheries share increased to 45%, more than double the corresponding 1980 share (20%). Dairy demand is also rising extremely rapidly (Fuller et al. 2006), and so it is clear by the trends that within a few years crop-related outputs will account for less than 50% of the total value of agricultural output in China.

Simultaneously with these changes, China has also experienced an explosion of market-oriented activities (Rozelle et al. 2000). While the pace of policy change was gradual throughout the 1980s and 1990s, the role of the state in China's agricultural markets has diminished. In its place there has been a rise of private traders and wholesale markets staffed by private traders (Huang, Rozelle, and Chang 2004). Wang et al. (2006) have documented the emergence of competitive markets in the horticultural sector, and the dairy and livestock sectors have followed this trend as well.

5. INPUTS, OUTPUTS, AND PRODUCTIVITY BEFORE 1995

The slowdown in the rate of growth of output experienced in the 1985-1994 period compared with the pace of growth in previous years as the Household Responsibility System came into force (McMillan, Whalley and Zhu 1989; Lin 1992) raised concerns among policymakers that the underlying rate of TFP growth had also slowed after 1984.[3] Notwithstanding these broad input, output, and productivity trends, our evidence suggests the general patterns of growth

[3]The relatively rapid growth in aggregate output during the late 1970s and early 1980s was coupled with a much slower growth in total input use, not least because much labor left the sector, resulting in a rapid growth in TFP (see, e.g., Fan and Zhang 2002).

do not necessarily reflect commodity-specific developments. For example, between 1985 and 1994, output growth for early and late indica rice and soybeans fell to less than 1% per year (Table 9.1, Column 1), while the total production of early indica rice actually declined. At the same time, the rate of growth of input use for these three crops was in the range of 1% to 2% per year; thus, the corresponding crop-specific TFP growth rates were low to negative.

In contrast, for other staple grain crops, including japonica rice, wheat, and corn, the slowdown in the rate of growth of output during the 1985-1994 period was less pronounced (such that output for these three crops still increased at rates in excess of 2% per year) and exceeded the rate of increase in input use. However, to the extent there is suitable evidence available, it appears that many of the commodities for which we have comparable data experienced a slowdown in their respective rates of TFP growth from the mid-1980s to mid-1990s. Cotton production fell by 0.06% per year while input use soared (by more than 3% per year)—reflecting responses to widespread pest outbreaks—such that TFP fell (Table 9.2, row 1). Input use rose more rapidly than output for hog production as well during this decade (Table 9.3, rows 1-3).

The input, output, and TFP growth assessment just presented demonstrates that the policy concerns regarding the relatively poor performance by Chinese agriculture during the decade of 1985-1994 were justified. Tables 9.4, 9.5, and 9.6 provide estimates of the rate and source of TFP change using the stochastic production function method previously described (and assuming linear input and

Table 9.1. Annual growth rate of output and total cost of production, main grain crop, 1985 to 2004

	1985-1994		1995-2004	
Crop	Output	Input	Output	Input
	(percent per year)			
Early indica	-0.37	2.00	0.58	-1.78
Late indica	0.42	2.30	0.67	-2.00
Japonica	2.30	1.21	1.88	-3.52
Wheat	2.04	1.89	1.01	0.21
Corn	2.06	0.30	0.86	-0.92
Soybeans	0.57	1.18	1.07	-0.89

Source: Authors' calculations based on National Agricultural Production Cost Survey data. See data section for an overview and Appendix D for complete annual series of cost of production at the national level.
Note: Growth rates generated by regression method.

Table 9.2. Annual growth rate of output and total cost of production cash crops (cotton and horticultural crops), 1985 to 2004

	1985-1994		1995-2004	
Crop	Output	Total Cost	Output	Total Cost
		(percent per year)		
Cotton	-0.06	3.42	2.81	-3.93
Horticultural crops				
Capsicum	n.a.	n.a.	2.87	2.22
Eggplant	n.a.	n.a.	1.47	2.90
Field cucumber	n.a.	n.a.	-0.40	-1.79
Field tomato	n.a.	n.a.	1.36	1.94
Greenhouse cucumber	n.a.	n.a.	1.11	0.60
Greenhouse tomato	n.a.	n.a.	2.95	1.50
Mandarin orange	n.a.	n.a.	1.30	0.13
Orange	n.a.	n.a.	-1.77	0.30

Source and note: See Table 9.1.

Table 9.3. Annual growth rate of output and total cost of production of livestock and dairy output, 1985 to 2004

	1985-1994		Early or Mid-1990s-2004	
Commodities	Output	Total Cost	Output	Total Cost
		(percent per year)		
Backyard hog production	1.24	2.47	5.29	-5.12
Specialized hog production	3.80	5.53	5.54	-5.37
Commercial hog production	0.29	0.86	13.05	-4.60
Specialized egg production	n.a.	n.a.	1.95	-1.87
Commercial egg production	n.a.	n.a.	2.43	-0.57
Beef production	10.2	-1.29	9.30	-0.92
Specialized milk	n.a.	n.a.	2.02	3.21
Commercial milk	n.a.	n.a.	5.19	0.71

Source and note: See Table 9.1.

output trends). This analysis estimates that TFP growth rates for early and late indica rice and soybeans during the 1985-1994 period were 1.84%, 1.85% and 0.11% per year, respectively (Table 9.4, Column 1). TFP growth estimates for wheat and corn were also positive (although small). In contrast (and somewhat at odds with the aforementioned relative input and output growth rates) we estimated TFP growth for japonica rice to have fallen by 0.12% per year from 1985 to 1994.

Table 9.4. Annual growth rate of main grain crops production and total factor productivity (TFP), and decomposition into technical efficiency (TE) and technical change (TC) in China, 1985 to 2004

	1985-1994			1995-2004		
	TFP	TE	TC	TFP	TE	TC
Early indica	1.84	-0.03	1.88	2.82	0	2.82
Late indica	1.85	0.26	1.59	2.92	0.21	2.71
Japonica	-0.12	-0.37	0.26	2.52	0.15	2.37
Wheat	0.25	1.08	-0.83	2.16	1.06	1.10
Corn	1.03	0.61	0.42	1.70	-0.23	1.94
Soybeans	0.11	0.19	-0.09	2.27	-0.08	2.35

Source and note: See Table 9.1.

Table 9.5. Annual growth of cash crops (cotton and horticultural crops) production and total factor productivity (TFP), and decomposition of TFP into technical efficiency (TE) and technical change (TC), 1985 to 2004

	Growth Rate (1980s-1990s)			Growth Rate (1990/91-2003)		
	TFP	TE	TC	TFP	TE	TC
Cotton	-0.34	-2.54	2.21	4.16	-3.47	7.63
Horticultural crops						
Capsicum	n.a.	n.a.	n.a.	1.86	-0.42	2.28
Eggplant	n.a.	n.a.	n.a.	2.24	-3.14	5.37
Field cucumber	n.a.	n.a.	n.a.	5.15	-1.27	6.42
Field tomato	n.a.	n.a.	n.a.	3.23	-0.50	3.73
Greenhouse cucumber	n.a.	n.a.	n.a.	5.86	0.62	5.24
Greenhouse tomato	n.a.	n.a.	n.a.	4.02	-2.43	6.45
Mandarin orange	n.a.	n.a.	n.a.	2.33	-2.19	4.52
Orange	n.a.	n.a.	n.a.	4.31	-3.20	7.50

Source and note: See Table 9.1.

The estimated sources of TFP growth vary among the crops. Positive technology change (albeit less than 2% annually in all cases) was a major influence on TFP growth for early and late indica rice and accounted for about half the measured growth in corn TFP. In contrast, some or all of the modest rises in TFP for wheat, corn, and soybeans are accounted for by increased technical efficiencies. While we cannot pinpoint the underlying sources of efficiency gains, these rates of increase are consistent with the measurements of deBrauw, Huang, and Rozelle (2004), which showed that the gradual liberalization of China's grain markets after 1985 generated efficiency gains for producers.

Table 9.6. Annual growth of livestock and dairy production and total factor productivity (TFP), and decomposition into technical efficiency (TE) and technical change (TC), 1985 to 2004

	Growth Rate (1980s-1990s)			Growth Rate (1990/91-2003)		
Products	**TFP**	**TE**	**TC**	**TFP**	**TE**	**TC**
Backyard hog production	4.80	1.26	3.54	3.72	1.01	2.72
Specialized hog production	5.58	-0.14	5.72	5.35	-0.72	6.07
Commercial hog production	5.67	0.09	5.58	4.40	-0.38	4.78
Specialized egg production	n.a	n.a	n.a	3.78	0.32	3.46
Commercial egg production	n.a	n.a	n.a	4.83	1.44	3.39
Beef production	n.a	n.a	n.a	4.41	0.01	4.40
Specialized milk	n.a	n.a	n.a	0.48	-6.09	6.58
Commercial milk	n.a	n.a	n.a	1.31	-3.26	4.57

Source and note: See Table 9.1.

The record is mixed for non-grain crops. The fall in cotton TFP (Table 9.5, Columns 1 to 3) shows that China's cotton production sector lost its international competitive edge during the 1985-1994 decade (as described in Huang et al. 2002). Although the research system helped stem the fall by producing some new conventional cotton varieties, the efficiency of production fell (likely because of the uncontrolled rise in the myriads of pesticides that appeared on the market to control for the emergence of the cotton bollworm population that was becoming increasingly resistant to conventional pesticides). Some of the new pesticides appear to have been ineffective (such that for a given level of input, output fell short of the production frontier—which by definition is measured as inefficiency). According to our estimates, changes in TFP for hog production were driven largely by improvements in technology, and, contrary to the direct input-output estimate previously discussed, the frontier production function approach has TFP growing during this period.

6. INPUTS, OUTPUTS, AND PRODUCTIVITY AFTER 1995

The relatively slow rates of growth of output experienced in 1985-1994, compared with the pace of growth in previous years, raised concerns that the underlying rate of TFP growth had systematically slowed after 1984. Thus far, information has been lacking on the pace of productivity growth for the major grain crops for the decade after 1995. In addition, there has never been a systematic analysis of the productivity performance of rapidly emerging agricultural sectors, such as horticulture, poultry, and dairy.

6.1. Outputs and Inputs after 1995

Agricultural output growth for most commodities rebounded during the period 1995-2004. For 20 of the 23 commodities for which we have more-complete data, output grew at a faster rate than inputs (Tables 9.1-9.3), so the TFP growth was positive for all these commodities (Tables 9.4-9.6). This was so for all the grain crops as well as for soybeans. Other sectors within agriculture showed similar trends. Cotton production expanded by 2.81% per year, whereas measured inputs declined by 3.93% per year, so that TFP grew by an impressive 4.16% per year. Most likely, the widespread uptake of Bt cotton—which allowed farmers to dramatically reduce pesticide use and labor for spraying while increasing yields—is a large part of the story. Setting aside the specialized milk sector that is mostly made up of large commercial dairies, the livestock sector also saw output growing faster than inputs during 1995-2004.

The horticultural sector has a more mixed record. The pace of output growth exceeded the pace of growth in input use for five of the horticultural crops, namely, capsicum, field cucumbers, greenhouse cucumbers, greenhouse tomatoes, and mandarins, whereas the opposite held for eggplants, field tomatoes, and oranges. The fact that greenhouse tomatoes and other greenhouse vegetables experienced positive rates of TFP growth compared with negative TFP growth for field tomatoes and some other crops might reflect the greater efficiencies of those commercial farmers who adopted greenhouse technologies.

6.2. TFP and Its Sources, 1995-2004

TFP growth during 1995-2004 was positive for all 23 commodities and in all cases was greater than the measured TFP for the pre-1995 period (Tables 9.4, 9.5, and 9.6). With just a few exceptions, TFP growth for these commodities exceeded 2% per year after 1994. In fact, using the respective value shares of output as weights when aggregating these 23 commodities, the implied rate of growth of TFP for Chinese agriculture exceeded 3% per year between 1995 and 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 increase in excess of 3% per year, a remarkable achievement over a quarter of a century (see also Jin et al. 2002).

Our estimates suggest that technical change was the dominant source of TFP growth during both 1978-1994 and 1995-2004. Technical change accounted for nearly all the TFP gains for soybeans and all the grain crops except wheat, and for wheat it accounted for about half the TFP growth (Table 9.4). These findings are consistent with the evidence presented by Jin et al. (2002), wherein the rate of uptake of locally bred varieties was substantial during the entire period 1978-2004.

The increasing share of TFP growth after 1995 in cotton and horticultural crops attributable to technical change is also indicative of the effects of domestic and foreign breeding efforts (Table 9.5). Notably Bt cotton varieties emanating from the Chinese Academy of Agricultural Sciences and foreign firms had measurable productivity-promoting effects in the Chinese cotton sector throughout this period (Huang et al. 2002). Similarly, the increased productivity-promoting effects of technical change in the Chinese horticultural sector appear to stem from the spread of new varieties, many of which were imported from foreign firms.

Foreign technologies also appear to have played a role in the rapidly increasing share of TFP growth in the livestock sector attributable to technical change in more recent times (Table 9.6). During the 1990s, China encouraged the importation of large amounts of new genetic material for the hog, beef, poultry, and dairy industries. The quality of the genetic stock in China's livestock industry has greatly increased through the introduction of new hog varieties from the United States and Japan; new beef and dairy cattle genetics from Canada, New Zealand, and Australia; and poultry technology from around the world, including the United States. Apparently these new innovations have found their way into individual farms in Chinese villages as well as in fledgling commercial operations.

Our evidence that an increasing share of TFP growth is attributable to changes in technology, be they new crop varieties, improved livestock breeds, or other innovations, nonetheless also exposes some serious weaknesses in Chinese agriculture. For more than one-half the commodities in our study (specifically 14 of 23), TFP growth would have been higher during 1995-2004 if producers had not become less efficient. Producers of corn, soybeans, cotton, seven of the eight horticultural crops, and half of the livestock commodities were less efficient in 2004 than they were in 1995. While the analysis cannot identify the specific sources of the fall in efficiency, we believe that the disintegration of the extension system may have contributed to the measured efficiency losses.

7. CONCLUSION

Our analysis shows that agricultural TFP in China grew at a relatively rapid rate since 1994 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. The rate of increase in agricultural TFP in China over the quarter century 1978-2004 was high by historical standards and compared with corresponding rates of TFP growth reported for many other countries around the world. We 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. Sustained and increasing support to Chinese agricultural research has been vital to this success, as has an openness to trade in technologies produced by public research agencies in foreign countries and foreign firms.

APPENDIX A: DATA DETAILS FOR THE LIVESTOCK TFP ANALYSIS

An ongoing problem for the study of livestock productivity in China is obtaining accurate data. The majority of studies of Chinese agricultural productivity have used data published in the *China Statistical Yearbook*. While this source disaggregates gross value of agricultural output into crops, animal husbandry, forestry, fishing, and sideline activities, input use is not disaggregated by sector. For this study we drew on additional farm-level data to facilitate the construction of a time-series of input use for livestock production, stratified by farm type. A further problem with livestock data from the statistical yearbooks is the apparent over-reporting of both livestock product output and livestock numbers (Fuller, Hayes, and Smith 2000). We also address this issue in this study.

We specify four inputs to livestock production, specifically, breeding animal inventories, labor, feed, and non-livestock capital. We describe in what follows our data construction methods as well as our approach to addressing the over-reporting of the count of animals on farm and livestock output.

Livestock Output

Concerns over the accuracy of official published livestock data include an increasing discrepancy over time between supply and consumption figures and a lack of consistency between livestock output data and that on feed availability. Ma, Huang, and Rozelle (2004—henceforth MHR) provided an adjusted series for livestock production (and consumption) that are internally consistent by recognizing that the published data do contain useful, albeit somewhat inconsistent, information. To adjust the published series, new information from several sources was introduced. Specifically, MHR used the 1997 National Census of Agriculture as a baseline to provide a more accurate benchmark estimate of the size of China's livestock economy for at least one time period. The census is taken to provide the most accurate estimate of the size of the livestock economy since it covers all rural households and non-household agricultural enterprises. The census also collected information on the number of slaughterings (by type) during the 1996 calendar year. A second source of additional information is the official rural Household Income and Expenditure Survey (HIES) that is maintained by the China National Bureau of Statistics (CNBS). Information collected in that survey includes the number of livestock slaughtered and the quantity of meat produced for swine, poultry, beef cattle, sheep and goats, and eggs. MHR assumed that the production data as published in the *China Statistical Yearbook* were accurate for the period 1980-1986. Beyond this date, the data are adjusted to both reflect the annual variation as found in the HIES data and to agree with the census data for 1996. Further details of these adjustment procedures can be found in MHR. The adjusted series includes provincial data on livestock production, inventories, and slaughterings.

Animals as Capital Input

Following traditional practices, we recognize the inventory of breeding animals as a major capital input to livestock production. Thus, opening inventories of sows, milking cows, laying hens, and female yellow cattle are used as capital inputs in the production functions for pork, milk, eggs, and beef, respectively. Provincial inventory data for sows, milking cows, and female yellow cattle are taken from official sources and adjusted for possible over-reporting as described earlier.

Additional problems exist with poultry inventories. China's yearbooks and other statistical publications contain poultry inventories aggregated over both layers and broilers. No official statistical sources publish separate data for layer hens. MHR (2004), however, provide adjusted data on egg production, and the State Development Planning Commission's Agricultural Commodity Cost and Return Survey provides estimates of egg yields per hundred birds. Thus, layer inventories, at both the national and provincial levels, are calculated by dividing output by yield.[4] A simple test shows that the sum across provinces of our provincial layer inventories is close to our estimate of the national layer inventory in each year.[5]

Feed, Labor, and Non-livestock Capital Inputs

Provincial data for these production inputs are obtained directly from the Agricultural Commodity Cost and Return Survey.[6] Thought to be the most comprehensive source of information for agricultural production in China, these data have been used in many other studies (e.g., Huang and Rozelle 1996; Jin et al. 2002). Within each province, a three-stage random sampling procedure is used to select sample counties, villages, and, finally, individual production units. Samples are stratified by income levels at each stage. The cost and return data collected from individual farms (including traditional backyard households, specialized households, state- and collective-owned farms, and other larger commercial operations) are aggregated to the provincial and national level data sets that are published by the State Development Planning Commission.

The survey provides detailed cost items for all major animal commodities, including those covered in this chapter. These data include labor inputs (days), feed consumption (grain equivalent), and fixed asset depreciation on a "per animal unit" basis. We deflated the depreciation data using a fixed asset price index. We calculated total feed, labor, and non-livestock capital inputs by multiplying the input per animal by animal numbers. For the latter, we used our slaughter numbers for hogs and beef cattle, and the opening inventories for milking cows and layers since these are the "animal units" used in the cost survey. It is clear that this procedure, necessitated by the available data, excludes some input usage.

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[4]The cost and return survey did not contain egg yields for every province for each of the past 15 years. Provincial trend regressions were used to estimate yields in such cases.

[5]Data on inventories of breeding broilers are available only from 1998, and we could not discover any way of deriving earlier data from the available poultry statistics. This severely limited our ability to analyze productivity developments in this sector.

[6]This survey is conducted through a joint effort of the State Development Planning Commission, the State Economic and Trade Commission, the Ministry of Agriculture, the State Forestry Administration, the State Light Industry Administration, the State Tobacco Administration, and the State Supply and Marketing Incorporation.

Livestock Production Structures

China's livestock sector is experiencing a rapid evolution in production structure, with potentially large performance differences across farm types. For example, traditional backyard producers utilize readily available low-cost feedstuffs, while specialized households and commercial enterprises feed more grain and protein meal. The trend from traditional backyard to specialized household and commercial enterprises in livestock production systems therefore implies an increasing demand for grain feed (Fuller, Tuan, and Wailes 2002). To estimate productivity growth by farm type requires that our data be disaggregated to that level. This was not a problem for the feed, labor, and nonlivestock capital variables, since they are recorded by production structure in the cost surveys. However, complete data on livestock output and animal inventories by farm type do not exist.

Our approach to generating output data by farm type was to first construct provincial "share sheets" that contained time-series data on the share of animal inventories (dairy cows and layers) and slaughterings (hogs) by each farm category (backyard, specialized, and commercial).[7] Inventories of sows by farm type were then generated by multiplying the aggregate totals (see earlier section) by the relevant farm-type hog slaughter share. We note that this assumes a constant slaughterings-to-inventory share across farm types for hog production and therefore assumes away a possible cause of productivity differences in this dimension across farm types. However, it proved impossible to gather further data to address this concern.

To disaggregate our adjusted livestock output data by farm type, it is important to take into account yield differences across production structures. From the cost surveys we obtained provincial time-series data on average production levels per animal (eggs per layer, milk per cow, and mean slaughter live weights for hogs). This information was then combined with the farm-type data on cow and layer inventories and hog slaughterings to produce total output estimates by farm type that were subject to further adjustment to ensure consistency with the aggregate adjusted output data.

Information that enabled us to estimate the inventory and slaughter shares by farm type and by province over time comes from a wide variety of sources. These include the 1997 China Agricultural Census, China's Livestock Statis-

[7]We did not disaggregate beef data by farm type, since the cost survey presented beef information for just a single category—rural households.

tics, a range of published materials (such as annual reports, authority speeches, and specific livestock surveys) from various published sources, and provincial statistical Web sites. The census publications provide an accurate picture of the livestock production structure in 1996 (Somwaru, Zhang, and Tuan 2003). However, the census defines just two types of livestock farms: rural households and agricultural enterprises (including state- and collective-owned farms). We interpret the latter as "commercial" units, but additional information is used to disaggregate the rural households into backyard and specialized units. The agricultural statistical yearbooks and China's Livestock Statistics provide data on livestock production structure during the early 1980s, when backyard production and state farms were prevalent. These sources, plus the animal husbandry yearbooks and provincial statistical Web sites also provide estimates of livestock shares for various livestock types, provinces, and years. When all these data are combined with 1996 values from the census, many missing values still existed. On the assumption that declining backyard production and increasing shares of specialized and commercial operations are gradual processes that evolved over the study period, linear interpolations were made to estimate a number of missing values.

APPENDIX B: DATA DETAILS FOR THE DAIRY SECTOR TFP ANALYSIS

Since dairy sector official statistics face the same over-reporting problem as described in Appendix A and the data adjustments for the dairy sector were not included in Ma, Huang, and Rozelle (MHR 2004), we have to adjust data on milk output and dairy cattle inventories before estimating dairy sector TFP. To maintain the consistency with the livestock commodities, we use a similar approach to adjust milk output and the dairy cattle numbers. In order to adjust the published series, new information from several sources is introduced.

First, the 1997 National Census of Agriculture is used as a baseline to provide an improved estimate of the size of China's dairy sector economy in at least one time period. As described in MHR, the census is assumed to provide the most accurate measure of dairy cattle inventory in 1996 since it covers all rural households and non-household agricultural enterprises.

Second, we also used the official annual HIES. Information collected in that survey includes the number of cows producing milk output.

We also assumed that the dairy cattle numbers and milk output data as published in the statistical yearbooks are accurate from 1980 to 1986. Beyond this date, we assume that the data are adjusted to both reflect the annual variation as found in the HIES data and to agree with the census data for 1996.

The adjustment procedure for dairy sector production data is the same as described in MHR. The adjusted series includes provincial data on dairy cattle inventory and milk output.

APPENDIX C: SUMMARY OF DATA SAMPLE SIZE

Table 9.C1. Summary of data sample and size

Commodity	Time Periods Covered	Provinces per Year: Minimum Number	Provinces per Year: Maximum Number	Total Observations
Hogs				
Backyard households	1980-2001	15	27	491
Specialized households	1980-2001	3	25	285
Commercial	1980-2001	2	25	224
Layers				
Specialized households	1991-2001	10	22	160
Commercial	1991-2001	8	16	132
Beef				
Rural households	1989-2001	4	10	97
Milk				
Specialized households	1992-2001	5	16	91
Commercial	1992-2001	10	23	155
Crops				
Corn	1985-2004	19	22	418
Wheat	1985-2004	21	25	459
Early rice	1985-2004	7	11	179
Late rice	1985-2004	4	9	155
Japonic	1985-2004	14	17	313
Soybeans	1985-2004	13	18	302
Cotton	1985-2004	14	17	308
Horticulture				
Capsicum	1990-2003	6	28	260
Eggplant	1990-2003	12	28	306
Field cucumber	1990-2003	10	26	266
Field tomato	1990-2003	9	25	259
Greenhouse cucumber	1990-2003	6	21	186
Greenhouse tomato	1990-2003	5	20	193
Mandarin	1990-2003	2	6	118
Orange	1990-2003	3	11	160

Note: Vegetable data include only urban areas of provincial capital cities.

APPENDIX D: COST OF PRODUCTION TABLES (ALL COST FIGURES ARE IN 1985 PRICES)

Table 9.D1. Yield, total cost, and major cost shares for corn production in China

Year	Yield	Output Per Man Day	Total Production Cost	Total Cost Share: Labor	Total Cost Share: Materials	Total Material Input Cost Share: Seeds	Organic Manure	Fertilizer Use	Plastic Sheet	Pesticides	Irrigation	Fence	Depreciation
	(kg/mu)	(kg)	(yuan/ton)	(percentage)		(percentage)							
1985	297	18	192	43.0	57.0	9.7	19.0	33.4	0.0	0.8	3.2	0.0	7.7
1986	311	19	178	41.2	58.8	10.3	10.0	38.6	0.0	1.4	3.9	0.0	7.8
1987	310	19	207	44.4	55.6	11.3	13.1	34.0	0.0	0.9	3.5	0.0	7.0
1988	313	19	198	43.2	56.8	10.1	12.6	36.4	0.0	1.0	3.2	0.0	7.6
1989	166	10	391	41.9	58.1	9.4	12.5	36.5	1.7	1.0	3.9	0.0	7.3
1990	358	21	200	42.5	57.5	12.2	11.8	38.1	2.5	1.6	2.8	0.0	6.1
1991	354	24	183	38.2	61.8	10.4	9.7	37.5	2.3	1.5	4.7	0.0	7.0
1992	351	21	198	44.0	56.0	10.3	8.9	38.4	3.5	2.0	4.3	0.0	7.3
1993	421	56	139	37.6	62.4	10.6	8.3	40.5	3.6	2.0	3.7	0.0	8.2
1994	367	25	199	41.8	58.2	12.3	6.4	39.6	1.5	2.4	5.7	0.0	6.7
1995	362	23	229	41.5	58.5	13.3	7.9	42.9	1.5	2.7	4.1	0.0	11.3
1996	381	24	232	45.3	54.7	13.4	7.8	43.8	2.4	2.4	4.3	0.0	10.6
1997	350	22	263	48.2	51.8	10.8	7.6	40.9	2.2	2.4	7.9	0.0	10.8
1998	384	27	219	47.8	52.2	11.8	8.5	43.9	2.7	3.0	5.7	0.0	7.9
1999	363	28	224	46.8	53.2	12.0	8.0	42.9	2.2	2.9	7.6	0.0	7.6
2000	351	28	226	47.3	52.7	11.1	7.3	41.9	1.8	3.0	8.3	0.0	6.6
2001	379	31	209	48.3	51.7	11.3	8.2	40.5	2.2	3.2	8.4	0.0	6.0
2002	393	34	206	46.2	53.8	14.6	7.4	40.7	1.8	3.3	6.7	0.0	5.8
2003	369	33	218	47.4	52.6	12.6	7.6	42.6	1.9	3.3	6.6	0.0	5.6
2004	424	42	205	46.4	53.6	12.8	6.6	46.0	1.1	3.5	5.7	0.1	4.7

Source: National Agricultural Production Cost Survey (various years).

Table 9.D2. Yield, total cost, and major cost shares for wheat production in China

Year	Yield	Output Per Man Day	Total Production Cost	Total Cost Share: Labor	Total Cost Share: Materials	Total Material Input Cost Share: Seeds	Organic Manure	Fertilizer Use	Plastic Sheet	Pesticides	Irrigation	Fence	Depreciation
	(kg/mu)	(kg)	(yuan/ton)	(percentage)		(percentage)							
1985	208	15	283	35.0	65.0	17.3	14.4	31.8	0.0	1.4	4.1	0.0	7.0
1986	203	15	313	39.8	60.2	18.1	14.1	31.1	0.0	1.5	5.0	0.0	6.6
1987	197	15	333	39.5	60.5	17.5	14.0	30.8	0.0	1.8	4.8	0.0	6.4
1988	215	16	301	40.0	60.0	16.7	14.1	31.0	0.0	1.7	4.9	0.0	6.6
1989	230	16	292	37.7	62.3	17.1	11.0	32.9	0.0	2.3	5.3	0.0	6.3
1990	217	17	312	33.6	66.4	17.9	10.1	34.7	0.0	2.8	4.5	0.0	5.5
1991	233	19	299	34.8	65.2	15.8	10.1	35.5	0.1	3.3	4.7	0.0	5.8
1992	256	20	298	38.5	61.5	14.8	9.0	34.8	0.1	3.3	6.3	0.0	6.0
1993	244	20	327	42.9	57.1	13.7	8.0	33.9	0.1	3.3	6.4	0.0	6.9
1994	153	6	365	13.5	86.5	15.0	7.3	34.6	0.1	3.0	7.2	0.0	6.4
1995	257	20	297	39.9	60.1	18.5	7.9	38.3	0.1	3.1	7.2	0.0	6.6
1996	261	21	338	39.5	60.5	18.0	7.1	40.0	0.4	3.8	7.3	0.0	5.4
1997	277	23	323	42.0	58.0	17.8	6.6	37.9	0.4	3.2	7.2	0.0	5.7
1998	246	23	337	40.3	59.7	17.1	6.9	38.4	0.6	3.3	8.2	0.0	6.1
1999	261	25	325	39.5	60.5	16.8	6.9	37.2	0.1	3.7	10.2	0.0	6.4
2000	261	27	310	37.5	62.5	15.6	5.7	34.1	0.1	3.2	10.5	0.0	5.5
2001	261	28	303	39.5	60.5	15.6	6.1	32.8	0.1	3.1	9.9	0.0	5.4
2002	262	28	311	39.7	60.3	15.2	6.1	34.4	0.1	3.6	10.0	0.0	5.3
2003	255	28	312	40.2	59.8	15.2	6.4	34.3	0.0	3.5	9.7	0.0	5.5
2004	340	42	251	37.8	62.2	14.0	5.9	36.3	0.0	3.7	9.4	1.1	2.4

Source: National Agricultural Production Cost Survey (various years).

Table 9.D3. Yield, total cost, and major cost shares for early indica production in China

Year	Yield	Output Per Man Day	Total Production Cost	Total Cost Share: Labor	Total Cost Share: Materials	Total Material Input Cost Share: Seeds	Organic Manure	Fertilizer Use	Plastic Sheet	Pesticides	Irrigation	Fence	Depreciation
	(kg/mu)	(kg)	(yuan/ton)	(percentage)		(percentage)							
1985	375	18	205	41.1	58.9	9.8	9.0	37.0	0.0	5.4	5.6	0.0	8.1
1986	372	18	195	39.8	60.2	10.1	9.0	37.1	0.0	5.3	5.3	0.0	8.2
1987	359	18	222	43.1	56.9	10.1	8.9	36.5	0.0	6.4	5.0	0.0	8.0
1988	351	18	230	39.3	60.7	9.0	9.5	39.0	0.0	6.1	5.2	0.0	7.4
1989	370	19	230	37.2	62.8	10.8	8.2	36.6	1.6	6.7	3.5	0.1	6.8
1990	389	21	223	37.1	62.9	9.8	8.8	36.3	1.5	6.9	4.6	0.1	7.2
1991	356	18	242	37.9	62.1	9.4	9.7	36.4	1.9	6.3	4.4	0.1	7.6
1992	360	20	223	42.1	57.9	9.7	7.5	38.5	1.8	6.2	4.4	0.3	7.9
1993	379	21	219	43.0	57.0	8.7	6.5	40.8	1.9	6.0	5.0	0.1	7.2
1994	359	21	263	47.2	52.8	8.8	7.4	36.3	1.8	5.6	4.9	0.1	9.2
1995	366	21	302	46.2	53.8	10.8	5.9	40.3	1.8	6.6	3.4	0.2	7.3
1996	398	21	318	50.2	49.8	9.4	5.6	39.2	1.9	6.5	4.9	0.2	6.4
1997	384	23	317	50.1	49.9	8.2	5.5	35.8	2.1	6.8	4.2	0.2	6.8
1998	351	24	296	49.1	50.9	8.9	6.1	37.8	2.5	7.3	5.0	0.4	7.7
1999	353	26	286	48.5	51.5	8.8	4.5	37.0	2.2	7.7	4.7	0.9	6.9
2000	373	29	261	50.1	49.9	8.4	4.7	35.2	2.3	7.7	5.8	0.4	7.2
2001	375	30	260	50.8	49.2	7.8	4.9	34.9	2.0	7.9	6.0	0.2	7.5
2002	364	31	264	50.4	49.6	8.4	4.1	34.5	2.0	7.5	5.5	0.3	7.6
2003	371	31	261	51.5	48.5	8.3	3.6	35.5	1.8	8.2	4.9	0.2	7.2
2004	393	34	263	46.4	53.6	7.5	4.3	33.4	2.0	9.4	4.8	0.0	7.8

Source: National Agricultural Production Cost Survey (various years).

Table 9.D4. Yield, total cost, and major cost shares for late indica production in China

Year	Yield	Output Per Man Day	Total Production Cost	Total Cost Share		Total Material Input Cost Share							
				Labor	Materials	Seeds	Organic Manure	Fertilizer Use	Plastic Sheet	Pesticides	Irrigation	Fence	Depreciation
	(kg/mu)	(kg)	(yuan/ton)	(percentage)		(percentage)							
1985	350	17	206	42.3	57.7	9.6	5.7	39.2	0.0	8.7	5.2	0.0	8.4
1986	333	16	213	41.2	58.8	9.2	5.9	40.3	0.0	7.7	3.7	0.0	9.1
1987	347	18	234	42.3	57.7	8.5	6.3	43.4	0.0	7.6	3.7	0.0	8.5
1988	315	16	269	38.0	62.0	7.7	6.3	43.5	0.0	8.6	3.6	0.0	8.0
1989	349	18	256	36.3	63.7	10.7	6.8	40.1	0.1	9.2	4.1	0.1	7.5
1990	374	19	235	39.4	60.6	10.2	6.1	37.6	0.0	10.0	4.6	0.3	7.6
1991	371	20	226	37.7	62.3	9.1	7.1	37.3	0.2	9.4	5.0	0.0	8.1
1992	364	20	229	41.2	58.8	9.0	6.4	37.7	0.1	8.9	4.4	0.0	9.6
1993	372	21	219	43.0	57.0	8.4	6.5	38.8	0.0	9.1	4.5	0.0	8.6
1994	356	21	259	43.6	56.4	9.7	6.1	36.6	0.0	8.4	4.9	0.3	8.8
1995	363	21	301	44.7	55.3	11.6	5.0	39.6	0.0	7.6	3.9	0.0	7.9
1996	361	21	317	50.7	49.3	9.7	4.6	40.4	0.1	8.8	4.2	0.0	7.9
1997	364	22	303	50.3	49.7	9.1	4.7	38.1	0.1	9.9	4.2	0.1	6.8
1998	380	26	264	49.9	50.1	9.2	5.0	37.5	0.3	9.8	4.6	0.0	9.4
1999	367	26	274	50.6	49.4	10.6	4.5	36.9	0.1	11.2	5.0	0.0	7.4
2000	365	28	266	50.8	49.2	9.3	4.4	35.3	0.1	11.1	6.0	0.1	7.0
2001	388	32	244	51.4	48.6	8.1	3.8	35.3	0.3	11.7	6.1	0.0	7.1
2002	370	31	231	46.2	53.8	9.3	3.8	35.5	0.2	11.1	5.0	0.0	7.5
2003	379	33	296	42.6	57.4	6.4	26.7	26.7	0.1	9.1	4.1	0.0	5.3
2004	398	35	265	43.9	56.1	7.6	3.9	36.2	0.3	12.6	5.3	0.0	6.7

Source: National Agricultural Production Cost Survey (various years).

Table 9.D5. Yield, total cost, and major cost shares for japonica production in China

Year	Yield	Output Per Man Day	Total Production Cost	Total Cost Share		Total Material Input Cost Share							
				Labor	Materials	Seeds	Organic Manure	Fertilizer Use	Plastic Sheet	Pesticides	Irrigation	Fence	Depreciation
	(kg/mu)	(kg)	(yuan/ton)	(percentage)		(percentage)							
1985	374	17	229	38.2	61.8	11.7	5.8	33.5	0.0	5.6	11.3	0.0	7.7
1986	419	19	196	36.9	63.1	12.3	5.3	30.4	0.0	6.8	11.0	0.0	8.0
1987	391	19	237	39.5	60.5	11.4	5.3	30.3	0.0	6.7	9.5	0.0	11.0
1988	406	19	220	38.7	61.3	11.6	6.0	34.2	0.0	7.4	11.4	0.0	2.7
1989	404	19	242	35.1	64.9	12.1	5.4	30.9	1.8	7.3	10.1	0.2	7.2
1990	435	21	234	32.9	67.1	12.0	5.3	31.0	2.0	7.2	10.1	0.3	6.1
1991	439	21	243	33.2	66.8	9.5	4.8	29.8	2.1	7.6	10.5	0.7	5.8
1992	435	22	249	33.9	66.1	10.1	4.6	28.9	2.6	6.9	10.2	0.6	6.3
1993	440	22	245	37.0	63.0	8.7	4.4	29.3	2.0	6.8	12.0	0.3	5.2
1994	449	23	280	37.2	62.8	9.4	4.2	29.1	1.9	7.2	13.1	0.5	5.0
1995	432	23	302	34.6	65.4	9.6	3.0	31.7	2.5	7.7	9.9	0.6	4.6
1996	463	24	305	38.4	61.6	10.4	4.8	31.1	2.1	6.9	9.6	0.3	4.7
1997	472	27	293	41.4	58.6	8.8	3.0	30.1	2.1	7.0	11.6	0.6	5.4
1998	722	55	157	37.5	62.5	7.9	3.9	31.7	2.4	8.4	15.4	0.5	5.6
1999	438	29	278	41.5	58.5	8.6	3.0	32.5	2.7	8.3	15.6	0.5	5.3
2000	451	30	258	44.3	55.7	8.1	2.9	30.4	2.1	8.6	17.0	0.4	5.6
2001	478	33	233	42.4	57.6	7.9	2.9	31.5	2.0	9.7	16.5	0.5	5.1
2002	482	36	233	39.9	60.1	7.8	3.4	30.0	2.0	8.9	19.0	0.6	5.6
2003	459	34	252	41.8	58.2	7.5	2.8	30.1	1.7	9.9	20.2	0.4	4.8
2004	507	49	235	37.6	62.4	6.6	2.8	32.9	1.8	11.3	13.8	0.1	4.5

Source: National Agricultural Production Cost Survey (various years).

Table 9.D6. Yield, total cost, and major cost shares for soybean production in China

				Total Cost Share		Total Material Input Cost Share							
Year	Yield	Output Per Man Day	Total Production Cost	Labor	Materials	Seeds	Organic Manure	Fertilizer Use	Plastic Sheet	Pesticides	Irrigation	Fence	Depreciation
	(kg/mu)	(kg)	(yuan/ton)	(percentage)						(percentage)			
1985	195	17	195	45.8	54.2	27.9	9.4	16.9	0.0	2.0	1.2	0.0	10.6
1986	199	17	183	44.3	55.7	30.1	5.7	18.7	0.0	1.7	1.7	0.0	10.5
1987	190	16	214	49.9	50.1	30.9	10.5	15.2	0.0	2.0	1.2	0.0	10.3
1988	191	16	211	46.8	53.2	30.3	8.9	17.3	0.0	2.3	1.4	0.0	9.9
1989	191	17	210	46.0	54.0	32.7	10.4	13.3	0.0	2.6	1.6	0.0	10.1
1990	201	17	216	48.5	51.5	30.1	10.0	17.8	0.0	2.8	0.8	0.0	9.6
1991	188	18	208	45.4	54.6	27.2	8.1	18.9	0.0	2.7	1.2	0.0	10.7
1992	191	18	219	48.0	52.0	30.3	8.4	20.2	0.2	3.7	1.7	0.0	8.8
1993	222	20	206	48.0	52.0	29.7	6.4	17.9	0.3	4.1	1.7	0.0	8.9
1994	217	20	208	49.6	50.4	26.2	6.4	22.1	0.3	4.3	3.5	0.0	8.5
1995	232	22	202	46.2	53.8	24.1	5.5	24.6	0.0	3.9	1.5	0.0	9.6
1996	242	21	236	48.8	51.2	25.5	6.6	24.5	0.0	3.6	1.9	0.0	7.5
1997	217	19	288	49.5	50.5	24.1	7.2	18.5	0.0	4.3	8.7	0.0	7.9
1998	258	28	184	54.3	45.7	29.9	8.4	25.3	0.0	5.2	5.3	0.0	13.6
1999	243	31	182	50.6	49.4	26.7	8.1	24.4	0.2	6.9	6.5	0.0	11.9
2000	242	33	181	46.8	53.2	26.1	4.2	21.1	0.0	7.1	5.2	0.0	9.8
2001	237	32	184	47.3	52.7	23.2	4.9	23.3	0.0	5.6	4.7	0.0	9.8
2002	267	37	165	48.4	51.6	23.1	4.0	24.2	0.0	6.8	6.1	0.0	10.2
2003	240	32	199	48.4	51.6	23.3	4.8	25.2	0.1	6.3	5.3	0.0	9.1
2004	260	50	201	40.7	59.3	21.1	1.9	27.4	0.0	8.2	1.6	0.2	7.9

Source: National Agricultural Production Cost Survey (various years).

Table 9.D7. Yield, total cost, and major cost shares for cotton production in China

Year	Yield	Output Per Man Day	Total Production Cost	Total Cost Share		Total Material Input Cost Share							
				Labor	Materials	Seeds	Organic Manure	Fertilizer Use	Plastic Sheet	Pesticides	Irrigation	Fence	Depreciation
	(kg/mu)	(kg)	(yuan/ton)	(percentage)		(percentage)							
1985	60	1.4	1978	53.8	46.2	6.2	17.2	29.1	0.0	11.9	3.4	0.0	7.6
1986	63	1.5	1744	52.2	47.8	6.5	15.8	29.4	0.0	12.0	4.2	0.0	7.3
1987	63	1.6	1979	54.8	45.2	6.8	12.8	30.7	0.0	12.1	3.8	0.0	6.9
1988	53	1.3	2325	53.7	46.3	6.3	11.8	30.6	0.0	15.6	3.9	0.0	7.0
1989	58	1.4	2207	51.5	48.5	6.6	12.0	30.0	0.0	22.0	3.8	0.0	5.6
1990	68	1.5	2145	53.5	46.5	6.3	11.8	29.5	5.5	18.2	3.3	0.5	6.6
1991	69	1.6	2188	49.8	50.2	5.8	9.3	28.9	6.5	17.7	4.8	0.4	6.1
1992	53	1.3	2867	50.7	49.3	5.1	8.9	28.8	7.2	20.4	5.1	0.3	5.1
1993	57	1.4	2667	53.1	46.9	5.9	8.5	29.4	7.3	20.2	4.8	0.3	5.0
1994	60	1.4	2942	56.9	43.1	5.9	7.7	30.6	6.2	21.2	5.1	0.3	5.0
1995	61	1.5	3006	54.2	45.8	6.0	7.9	32.5	6.0	21.7	4.6	0.2	4.5
1996	61	1.5	3312	60.8	39.2	6.1	8.2	34.9	6.4	18.5	5.0	0.3	4.6
1997	65	1.7	3111	60.9	39.1	6.5	5.7	33.5	6.4	18.2	7.3	0.2	4.2
1998	68	2.0	2732	58.4	41.6	6.9	7.6	30.7	6.7	19.9	7.0	0.3	4.6
1999	67	2.2	2495	57.5	42.5	8.2	7.4	33.4	6.2	17.4	8.1	0.2	4.7
2000	71	2.5	2265	57.7	42.3	8.3	7.0	33.9	6.4	17.7	8.2	0.2	4.8
2001	78	2.6	2070	58.6	41.4	9.5	6.4	33.1	7.1	16.6	8.7	0.2	4.4
2002	82	2.8	1995	58.9	41.1	9.6	5.5	36.4	6.2	15.4	9.7	0.1	4.4
2003	68	2.5	2425	56.3	43.7	10.1	6.2	35.1	6.9	15.6	9.1	0.1	4.3
2004	76	3.1	2350	56.9	43.1	11.6	5.0	37.9	6.9	12.1	8.3	0.0	5.5

Source: National Agricultural Production Cost Survey (various years).

Table 9.D8. Yield, total cost, and major cost shares for capsicum production

Year	Yield	Output Per Man Day	Total Production Cost	Total Cost Share: Labor	Total Cost Share: Materials	Total Material Input Cost Share: Seeds	Organic Manure	Fertilizer Use	Plastic Sheet	Pesticides	Irrigation	Fence	Depreciation
	(kg/mu)	(kg)	(yuan/ton)	(percentage)		(percentage)							
1990	1543.2	51.2	318.0	28.3	71.7	25.8	16.8	9.1	21.8	3.6	2.5	4.0	5.7
1991	1243.9	54.7	335.6	27.6	72.4	20.9	15.6	10.8	22.0	4.3	3.3	7.0	4.8
1992	1545.3	155.2	561.2	51.7	48.3	18.4	14.5	11.6	18.8	5.2	2.6	3.8	4.8
1993	1970.4	73.3	364.7	39.6	60.4	14.5	18.2	12.0	18.0	4.7	8.8	0.6	5.7
1994	1421.7	62.1	321.6	45.2	54.8	24.7	14.9	15.4	16.5	6.1	3.6	3.5	4.2
1995	1540.8	54.8	341.1	42.9	57.1	16.9	20.3	13.5	18.2	7.6	2.8	3.5	4.5
1996	1793.3	66.8	424.0	53.2	46.8	17.8	19.2	16.6	15.2	7.4	4.0	3.0	6.3
1997	1692.4	64.4	405.1	52.7	47.3	9.9	13.4	17.1	20.6	6.9	3.3	5.9	8.4
1998	2021.7	58.2	382.2	52.7	47.3	15.8	17.5	21.3	18.4	7.7	3.1	6.4	5.6
1999	2206.0	57.4	413.3	53.4	46.6	12.4	18.5	18.6	18.3	10.3	4.0	6.1	6.1
2000	1971.9	49.9	368.4	49.9	50.1	14.6	17.4	18.6	17.1	10.7	4.9	5.4	4.5
2001	2067.9	46.0	393.6	51.9	48.1	14.2	23.0	18.0	13.7	9.9	4.6	4.7	5.0
2002	2227.4	44.9	397.4	53.6	46.4	13.8	19.6	20.0	14.8	10.2	4.5	6.3	4.9
2003	2312.3	45.8	424.5	53.5	46.5	12.6	19.1	20.3	14.7	10.9	4.8	6.3	5.2
2004	2408.8	44.1	390.5	46.5	53.5	12.9	18.5	24.4	6.9	10.5	5.1	2.8	2.8

Source: National Agricultural Production Cost Survey (various years).

Table 9.D9. Yield, total cost, and major cost shares for eggplant production

Year	Yield	Output Per Man Day	Total Production Cost	Total Cost Share: Labor	Total Cost Share: Materials	Total Material Input Cost Share: Seeds	Organic Manure	Fertilizer Use	Plastic Sheet	Pesticides	Irrigation	Fence	Depreciation
	(kg/mu)	(kg)	(yuan/ton)	(percentage)		(percentage)							
1990	2573.4	60.0	289.6	36.4	63.6	16.8	17.9	12.7	19.9	5.3	5.0	2.8	7.0
1991	2132.4	54.1	279.0	32.9	67.1	13.2	16.8	12.3	21.7	4.5	5.2	4.0	6.5
1992	2602.5	67.0	320.6	39.1	60.9	16.4	16.6	12.1	14.5	12.4	3.1	2.5	7.8
1993	2288.5	60.5	270.8	44.0	56.0	15.8	17.0	13.1	14.3	4.9	6.1	0.9	8.8
1994	1998.1	65.0	317.2	48.4	51.6	18.0	16.8	12.1	17.4	5.6	3.6	3.2	6.5
1995	2382.6	78.6	398.8	54.5	45.5	14.0	18.8	17.4	16.9	7.0	3.6	2.6	6.6
1996	2514.0	53.9	350.6	53.3	46.7	15.9	18.0	21.3	11.2	5.9	4.6	4.9	6.8
1997	2620.5	62.3	389.3	54.2	45.8	11.1	18.4	19.5	16.3	7.4	3.8	5.1	5.1
1998	2782.5	56.0	382.4	52.7	47.3	9.7	22.7	19.1	19.7	6.8	2.9	5.7	5.7
1999	3258.4	63.2	431.9	56.9	43.1	11.2	21.9	20.7	16.7	6.8	4.0	4.9	6.5
2000	2887.6	53.1	361.1	55.9	44.1	11.4	17.0	22.7	18.3	9.7	4.7	4.4	5.1
2001	3256.0	51.5	409.1	57.4	42.6	10.9	18.7	24.8	12.7	11.9	4.5	4.2	5.3
2002	3320.9	45.6	399.3	55.9	44.1	9.2	16.7	23.4	14.3	11.8	5.0	6.7	5.5
2003	3239.7	46.9	423.7	55.9	44.1	9.1	19.6	23.6	15.0	10.6	3.9	6.7	5.8
2004	3503.5	46.1	391.2	47.5	53.3	8.8	16.5	25.6	6.1	10.8	4.7	3.4	3.5

Source: National Agricultural Production Cost Survey (various years).

Table 9.D10. Yield, total cost, and major cost shares for greenhouse cucumber production

				Total Cost Share		Total Material Input Cost Share							
Year	Yield	Output Per Man Day	Total Production Cost	Labor	Materials	Seeds	Organic Manure	Fertilizer Use	Plastic Sheet	Pesticides	Irrigation	Fence	Depreciation
	(kg/mu)	(kg)	(yuan/ton)	(percentage)		(percentage)							
1990	4740.5	126.0	1,035.2	21.4	78.6	11.6	10.3	8.2	35.2	7.7	1.7	11.9	2.2
1991	4657.7	131.6	965.5	23.1	76.9	8.9	10.6	7.5	31.8	5.7	1.9	12.9	7.4
1992	3440.1	162.3	1,250.3	24.3	75.7	9.1	10.2	9.2	26.1	6.0	2.0	10.6	7.7
1993	3628.4	101.7	663.2	30.2	69.8	13.4	9.5	8.5	26.6	6.4	2.8	10.9	7.4
1994	3980.9	122.9	902.9	30.2	69.8	8.0	6.4	7.9	30.7	5.0	5.3	10.1	9.0
1995	4042.8	127.2	953.3	37.0	63.0	5.1	10.4	10.2	24.1	7.0	3.6	9.0	13.4
1996	4114.9	100.1	1,128.1	31.2	68.8	9.6	9.2	7.8	31.0	6.2	2.3	9.6	13.3
1997	4133.9	92.5	974.2	35.3	64.7	10.4	7.9	8.6	33.3	6.6	2.2	8.3	11.7
1998	4830.5	90.0	769.9	40.0	60.0	3.7	12.0	11.1	33.6	7.0	2.7	15.4	7.7
1999	4836.2	93.2	878.9	40.8	59.2	5.3	13.1	12.7	24.7	8.9	3.3	13.6	11.1
2000	4746.5	84.9	820.5	37.5	62.5	4.7	12.5	11.1	29.0	7.5	3.3	12.1	9.0
2001	4592.7	83.6	829.4	41.1	58.9	5.4	11.9	13.2	27.5	7.1	3.2	14.8	11.5
2002	4912.0	83.3	846.3	44.0	56.0	6.5	11.2	13.6	25.1	7.7	3.8	14.6	11.3
2003	4819.2	86.3	878.5	47.2	52.8	7.5	11.5	13.4	25.2	7.0	3.6	12.9	13.2
2004	4775.2	76.3	820.1	38.7	61.3	6.1	11.5	13.0	22.9	7.2	3.4	5.3	19.2

Source: National Agricultural Production Cost Survey (various years).

Table 9.D11. Yield, total cost, and major cost shares for greenhouse tomato production

				Total Cost Share		Total Material Input Cost Share							
Year	Yield	Output Per Man Day	Total Production Cost	Labor	Materials	Seeds	Organic Manure	Fertilizer Use	Plastic Sheet	Pesticides	Irrigation	Fence	Depreciation
	(kg/mu)	(kg)	(yuan/ton)	(percentage)		(percentage)							
1990	4147.9	120.7	732.8	28.9	71.1	6.2	13.6	7.4	35.5	6.4	2.0	8.5	5.0
1991	4127.8	128.4	820.5	26.6	73.4	11.4	11.9	7.9	37.3	4.9	1.6	8.8	6.8
1992	4171.0	146.1	788.7	34.7	65.3	8.6	10.0	8.7	32.1	4.5	2.0	11.8	8.4
1993	4365.0	132.2	863.9	30.1	69.9	9.1	8.5	10.0	25.7	5.9	3.7	14.9	12.2
1994	3997.1	141.2	909.9	37.1	62.9	9.6	8.2	9.8	30.3	4.4	3.2	11.5	8.6
1995	4268.7	125.9	913.8	36.8	63.2	5.9	10.0	9.3	31.7	6.1	2.1	10.1	13.5
1996	4676.1	108.7	961.4	40.8	59.2	9.4	11.9	10.4	30.4	5.2	2.4	12.4	5.9
1997	4643.5	115.1	1,015.4	42.4	57.6	3.5	9.0	9.2	29.3	5.6	2.8	8.6	16.7
1998	4575.0	90.4	772.4	43.8	56.2	4.8	12.4	11.5	30.8	6.7	2.1	15.6	11.6
1999	4658.7	92.2	816.0	44.8	55.2	6.6	11.5	12.7	27.7	6.1	2.7	11.1	15.2
2000	4907.1	90.0	850.2	39.0	61.0	4.2	10.5	10.9	28.0	5.5	2.7	13.0	15.3
2001	5074.4	88.2	891.5	40.3	59.7	4.7	12.3	11.5	28.0	7.1	3.0	15.7	13.6
2002	4796.1	85.6	852.3	45.5	54.5	5.6	12.7	12.9	25.7	6.9	3.6	15.7	12.5
2003	4761.2	84.9	876.4	46.6	53.4	5.7	11.9	13.6	25.0	7.9	2.8	13.6	15.0
2004	5088.7	79.5	966.3	43.9	56.1	5.6	10.7	14.3	22.0	7.1	2.7	6.0	21.9

Source: National Agricultural Production Cost Survey (various years).

Table 9.D12. Yield, total cost, and major cost shares for field cucumber production

Year	Yield	Output Per Man Day	Total Production Cost	Total Cost Share: Labor	Total Cost Share: Materials	Total Material Input Cost Share: Seeds	Organic Manure	Fertilizer Use	Plastic Sheet	Pesticides	Irrigation	Fence	Depreciation
	(kg/mu)	(kg)	(yuan/ton)	(percentage)		(percentage)							
1990	2850.9	79.0	377.7	36.7	63.3	12.3	14.5	8.9	17.8	6.3	3.4	18.1	5.7
1991	2656.6	69.5	356.6	33.1	66.9	11.0	15.5	8.7	22.0	7.4	3.0	15.7	3.6
1992	2872.6	86.2	483.2	33.4	66.6	12.9	11.8	9.7	19.8	6.0	2.9	14.3	5.7
1993	2742.6	72.7	386.2	37.0	63.0	9.2	14.5	10.1	15.0	7.5	3.7	17.6	6.5
1994	2698.5	76.6	387.2	46.0	54.0	13.2	15.5	12.8	15.0	6.4	2.7	14.5	4.7
1995	2561.6	70.9	390.6	50.7	49.3	8.6	16.8	12.0	13.7	9.2	3.6	16.5	3.0
1996	2700.2	67.8	430.8	55.0	45.0	8.9	21.8	18.6	6.3	9.4	2.8	14.6	4.1
1997	2653.9	65.5	406.8	52.5	47.5	9.2	14.2	17.4	9.4	10.6	5.8	12.2	4.1
1998	2897.0	54.8	349.9	54.9	45.1	7.9	15.5	22.1	6.8	8.3	4.1	21.9	4.8
1999	3281.1	59.1	407.6	54.0	46.0	10.0	17.1	26.5	8.7	8.5	5.0	15.4	4.7
2000	3235.5	52.8	363.5	51.8	48.2	10.3	16.5	20.4	8.1	14.4	4.4	15.7	3.6
2001	3396.3	46.8	392.4	52.6	47.4	10.0	20.4	20.4	6.1	13.8	5.0	13.0	4.3
2002	3527.6	49.7	414.5	55.1	44.9	10.1	19.5	20.1	7.2	13.2	5.6	13.5	4.7
2003	3413.7	47.3	418.0	54.4	45.6	10.7	17.5	22.5	7.1	13.6	5.3	14.1	4.1
2004	3661.8	48.3	426.3	46.3	53.7	8.9	16.2	23.2	5.3	13.5	4.8	8.7	3.3

Source: National Agricultural Production Cost Survey (various years).

Table 9.D13. Yield, total cost, and major cost shares for field tomato production

Year	Yield	Output Per Man Day	Total Production Cost	Total Cost Share: Labor	Total Cost Share: Materials	Total Material Input Cost Share: Seeds	Organic Manure	Fertilizer Use	Plastic Sheet	Pesticides	Irrigation	Fence	Depreciation
	(kg/mu)	(kg)	(yuan/ton)	(percentage)		(percentage)							
1990	2841.2	84.7	397.2	37.4	62.6	18.0	11.6	8.2	26.8	4.8	2.3	11.4	6.4
1991	2504.7	68.7	331.1	35.2	64.8	14.9	16.1	9.9	21.9	4.6	3.3	13.4	5.0
1992	3342.3	83.4	426.6	36.6	63.4	12.0	15.1	12.4	21.3	7.8	2.2	10.1	4.4
1993	2804.8	91.0	427.7	41.9	58.1	13.9	15.7	9.9	19.7	5.3	3.1	9.2	5.2
1994	3062.0	85.7	387.5	49.3	50.7	12.8	13.6	13.8	15.3	7.0	2.8	10.4	5.8
1995	3001.3	78.6	448.2	46.3	53.7	13.0	15.4	19.2	9.8	7.9	2.7	7.9	5.1
1996	2955.2	83.6	507.8	54.4	45.6	13.1	15.4	19.9	9.3	6.7	3.1	13.6	4.1
1997	3700.9	83.7	505.5	54.7	45.3	8.5	15.5	19.1	9.0	9.0	3.8	10.8	5.1
1998	3320.4	63.5	398.7	54.4	45.6	9.4	17.6	24.1	5.5	10.4	3.1	18.0	4.8
1999	4036.6	65.5	445.3	53.6	46.4	8.6	19.1	22.5	9.7	9.1	3.4	15.7	5.8
2000	3828.4	65.6	452.6	52.5	47.5	9.2	15.1	24.0	8.8	13.3	5.6	13.7	4.1
2001	4236.5	65.2	497.7	57.7	42.3	8.9	15.6	22.5	6.6	15.5	5.7	13.8	4.7
2002	4086.7	57.4	457.7	58.4	41.6	10.8	16.6	21.6	6.3	12.9	5.2	15.2	5.2
2003	4078.3	54.3	466.8	56.3	43.7	12.2	16.3	24.1	6.2	13.8	4.0	13.8	3.9
2004	4425.4	56.6	482.2	47.7	52.3	10.1	16.3	20.6	5.8	12.6	4.4	6.0	3.0

Source: National Agricultural Production Cost Survey (various years).

Table 9.D14. Yield, total cost, and major cost shares for mandarin (Guanggan) production

Year	Yield	Output Per Man Day	Total Production Cost	Total Cost Share: Labor	Total Cost Share: Materials	Total Material Input Cost Share: Seeds	Organic Manure	Fertilizer Use	Plastic Sheet	Pesticides	Irrigation	Fence	Depreciation
	(kg/mu)	(kg)	(yuan/ton)	(percentage)		(percentage)							
1985	1463	13	427.0	39.5	60.5	0.0	33.1	18.5	0.0	17.7	1.2	0.0	7.0
1986	1155	12	362.1	37.9	62.1	0.0	30.7	17.1	0.0	18.5	1.3	0.0	9.5
1987	1569	16	455.8	37.6	62.4	0.0	37.4	14.2	0.0	20.9	0.9	0.0	6.2
1988	995	11	424.9	35.1	64.9	0.0	34.5	13.1	0.0	24.2	1.0	0.0	7.6
1989	1585	16	471.9	33.7	66.3	0.0	22.7	22.6	0.0	28.8	0.9	0.0	8.1
1990	-	-	-	-	-	-	-	-	-	-	-	-	-
1991	1379	16	410.4	34.7	65.3	0.0	14.1	33.3	6.4	20.0	0.9	0.4	9.2
1992	1492	19	400.7	37.1	62.9	0.0	8.6	36.5	2.3	22.3	1.5	0.6	12.2
1993	1280	21	346.9	34.5	65.5	1.5	13.2	33.1	3.4	28.0	1.8	0.4	3.9
1994	1165	22	281.8	45.8	54.2	0.6	17.5	36.9	1.2	19.3	2.3	0.2	4.6
1995	1136	22	316.6	41.2	58.8	0.4	12.4	33.0	0.0	19.5	1.7	0.4	8.5
1996	1131	23	372.8	43.7	56.3	2.7	12.0	36.0	0.1	17.6	1.4	0.5	5.3
1997	1540	29	358.1	47.3	52.7	0.1	19.3	38.8	0.1	19.4	1.6	0.1	2.0
1998	1292	22	386.1	51.9	48.1	2.0	16.1	40.2	3.3	29.6	1.0	0.2	3.0
1999	1731	38	340.7	48.5	51.5	1.6	14.0	43.8	0.3	30.2	1.8	0.1	4.1
2000	1383	32	338.5	47.2	52.8	1.3	21.4	37.0	1.3	28.7	2.0	0.0	4.4
2001	1699	39	374.8	45.3	54.7	0.6	19.0	32.7	0.6	26.4	1.9	0.0	8.5
2002	1601	26	570.6	46.0	54.0	0.3	21.0	36.8	0.6	26.4	1.1	0.0	8.8
2003	2387	34	702.8	41.2	58.8	0.2	12.7	42.9	0.2	24.7	2.0	0.0	8.5

Source: National Agricultural Production Cost Survey (various years).

Table 9.D15. Yield, total cost, and major cost shares for orange (Juzi) production

Year	Yield	Output Per Man Day	Total Production Cost	Total Cost Share: Labor	Total Cost Share: Materials	Total Material Input Cost Share: Seeds	Organic Manure	Fertilizer Use	Plastic Sheet	Pesticides	Irrigation	Fence	Depreciation
	(kg/mu)	(kg)	(yuan/ton)	(percentage)		(percentage)							
1985	1348	16	282.0	45.0	55.0	0.0	19.1	2.3	0.0	12.9	3.9	0.0	5.8
1986	-	-	-	-	-	-	-	-	-	-	-	-	-
1987	-	-	-	-	-	-	-	-	-	-	-	-	-
1988	946	12	307.8	41.2	58.8	0.0	40.4	4.8	0.0	20.8	0.8	0.0	8.6
1989	1902	19	420.7	38.0	62.0	0.0	13.2	30.4	0.0	23.8	1.0	0.0	7.6
1990	-	-	-	-	-	-	-	-	-	-	-	-	-
1991	1823	27	319.1	36.0	64.0	0.1	9.5	31.9	1.2	24.9	0.4	0.0	9.5
1992	1751	24	396.8	35.0	65.0	1.6	12.3	27.4	0.0	19.1	2.5	0.0	9.0
1993	1963	23	396.8	43.1	56.9	0.7	10.7	29.0	0.1	33.6	1.4	0.5	4.3
1994	1673	24	360.3	51.0	49.0	1.0	12.8	31.9	0.0	24.9	0.7	0.3	5.6
1995	2035	29	350.3	50.1	49.9	2.8	5.3	36.3	0.6	22.3	1.3	0.2	3.0
1996	1557	29	381.0	51.6	48.4	0.9	4.2	45.0	0.1	25.9	1.0	0.1	8.0
1997	1963	45	260.6	53.1	46.9	0.2	10.3	35.6	0.4	26.3	9.8	0.3	5.8
1998	1239	43	181.1	50.6	49.4	2.3	14.5	44.3	0.1	23.0	1.1	0.7	6.2
1999	1676	33	425.6	49.4	50.6	1.1	14.8	38.6	0.8	33.2	0.4	0.0	6.7
2000	1193	32	255.1	54.7	45.3	0.2	16.8	38.1	0.0	30.4	2.1	0.0	7.2
2001	1240	32	332.2	50.0	50.0	7.7	11.8	35.0	0.0	33.9	1.0	0.1	6.4
2002	1521	37	380.8	49.0	51.0	0.6	15.6	37.2	0.0	35.8	0.4	0.0	6.5
2003	1819	42	383.2	52.4	47.6	0.4	14.0	40.7	0.0	35.2	0.4	0.0	4.9

Source: National Agricultural Production Cost Survey (various years).

Table 9.D16. Yield, total cost, and major cost shares for backyard hog production

Year	Yield	Output Per Man Day	Total Production Cost	Total Cost Share: Labor	Total Cost Share: Materials	Total Material Input Cost Share: Baby Animal	Fine Feed	Fodder	Feed Process	Depreciation
	(kg/per animal)	(kg)	(yuan/ton)	(percentage)				(percentage)		
1985	112.3	5.3	190.9	16.9	83.1	25.0	44.6	18.9	5.9	1.4
1986	109.2	5.2	194.7	16.4	83.6	19.7	50.1	18.7	5.3	1.6
1987	106.7	4.9	218.5	19.5	80.5	20.5	48.0	20.6	5.2	1.8
1988	121.1	5.4	271.5	15.8	84.2	24.8	52.2	13.8	2.7	1.2
1989	112.5	6.0	247.9	12.4	87.6	24.8	52.2	13.8	1.8	1.2
1990	114.1	5.3	224.5	17.9	82.1	24.3	50.9	15.0	1.5	1.4
1991	112.5	6.2	224.4	16.7	83.3	26.8	51.7	13.1	1.2	1.4
1992	116.1	6.0	214.7	19.1	80.9	27.6	49.4	12.9	1.7	1.3
1993	109.2	6.4	202.9	16.5	83.5	25.6	53.3	11.3	1.5	1.4
1994	106.6	5.2	255.1	19.4	80.6	27.1	53.2	10.9	1.5	1.2
1995	107.0	6.1	267.6	15.7	84.3	25.3	57.8	9.6	1.1	1.0
1996	105.3	8.3	229.2	15.7	84.3	26.8	54.4	10.5	1.0	1.2
1997	109.2	6.4	246.7	20.0	80.0	33.1	47.1	10.9	1.8	1.1
1998	109.2	7.1	227.5	20.0	80.0	29.7	50.9	11.1	1.6	1.2
1999	105.1	7.7	182.8	22.6	77.4	23.3	55.0	12.1	1.5	1.6
2000	105.9	8.3	179.3	21.5	78.5	27.4	52.1	11.3	1.6	1.5
2001	107.6	8.3	187.2	22.5	77.5	28.2	52.4	10.4	1.4	1.8
2002	105.5	9.1	178.6	21.6	78.4	27.0	54.6	9.5	1.4	1.7
2003	106.7	8.8	192.1	21.6	78.4	26.5	56.2	9.3	1.5	1.3
2004	107.4	9.7	230.6	18.9	81.1	31.2	53.1	8.2	1.2	1.1

Source: National Agricultural Production Cost Survey (various years).

Table 9.D17. Yield, total cost, and major cost shares for specialized hog production

Year	Yield	Output Per Man Day	Total Production Cost	Total Cost Share		Total Material Input Cost Share				
				Labor	Materials	Baby Animal	Fine Feed	Fodder	Feed Process	Depreciation
	(kg/per animal)	(kg)	(yuan/ton)	(percentage)				(percentage)		
1985	95.7	9.5	143.4	11.2	88.8	27.1	54.1	9.8	2.6	1.8
1986	95.7	10.4	156.8	8.7	91.3	23.7	58.3	9.4	2.2	1.8
1987	94.8	12.0	175.9	9.8	90.2	24.3	56.3	9.9	1.8	2.2
1988	106.4	7.9	233.1	11.0	89.0	19.2	42.5	7.0	1.1	1.5
1989	105.7	10.0	195.3	9.1	90.9	23.8	50.3	7.7	0.9	1.7
1990	105.1	13.8	187.7	7.4	92.6	27.1	56.0	8.2	0.8	1.8
1991	102.1	20.1	194.4	5.4	94.6	31.4	50.8	7.2	0.6	1.7
1992	107.4	11.3	197.7	10.1	89.9	28.6	54.3	6.5	0.9	2.3
1993	101.4	11.9	178.5	9.4	90.6	25.6	56.7	6.6	1.1	2.6
1994	94.2	10.9	229.2	9.3	90.7	28.6	57.5	3.5	0.8	1.4
1995	103.7	13.1	247.1	7.3	92.7	25.8	59.5	6.6	0.7	1.4
1996	103.0	15.1	229.5	8.8	91.2	28.0	58.5	6.0	0.4	1.5
1997	104.8	16.4	237.3	8.5	91.5	36.9	50.3	5.1	0.8	1.5
1998	99.8	21.7	204.1	6.9	93.1	29.0	61.2	2.8	0.8	2.1
1999	96.1	22.2	162.6	8.8	91.2	25.1	62.5	4.7	0.8	1.9
2000	101.7	16.4	156.4	12.2	87.8	28.8	56.0	7.2	0.9	1.6
2001	-	-	-	-	-	-	-	-	-	-
2002	95.8	21.3	153.8	9.3	90.7	27.2	59.9	4.9	1.1	1.7
2003	98.9	16.8	170.3	11.8	88.2	26.7	61.5	4.7	1.1	1.5
2004	102.5	18.4	217.9	10.6	89.4	31.2	57.8	3.7	0.8	1.5

Source: National Agricultural Production Cost Survey (various years).

Table 9.D18. Yield, total cost, and major cost shares for state-collective hog production

Year	Yield	Output Per Man Day	Total Production Cost	Total Cost Share: Labor	Total Cost Share: Materials	Total Material Input Cost Share: Baby Animal	Fine Feed	Fodder	Feed Process	Depreciation
	(kg/per animal)	(kg)	(yuan/ton)	(percentage)		(percentage)				
1985	105.4	12.2	186.2	8.8	91.2	28.1	55.9	8.4	1.4	1.9
1986	107.7	14.6	217.1	6.6	93.4	31.1	56.1	5.3	1.0	1.7
1987	110.7	19.7	255.1	4.7	95.3	33.6	56.2	2.7	0.7	1.6
1988	113.0	26.2	247.9	3.7	96.3	34.8	56.3	1.4	0.5	1.5
1989	98.7	28.0	214.9	2.7	97.3	34.8	56.3	1.4	0.5	1.5
1990	99.7	29.5	201.7	3.2	96.8	30.4	58.5	1.9	0.5	1.7
1991	96.6	32.3	197.4	3.3	96.7	38.7	50.3	1.5	0.7	1.5
1992	103.8	16.6	214.6	6.3	93.7	28.1	59.3	2.1	0.3	2.3
1993	105.0	20.0	187.4	5.5	94.5	20.6	67.7	0.9	0.4	2.3
1994	95.3	16.0	228.7	7.5	92.5	23.2	63.2	3.3	0.5	1.8
1995	99.5	16.5	255.0	6.8	93.2	25.2	63.0	3.0	0.3	1.8
1996	98.0	16.9	253.6	7.7	92.3	24.1	64.1	0.6	0.5	2.2
1997	96.2	18.2	257.4	7.7	92.3	31.9	56.8	0.9	0.4	2.2
1998	94.4	23.4	212.0	6.7	93.3	29.7	59.4	2.6	0.7	2.5
1999	94.1	48.3	173.7	4.2	95.8	28.9	61.0	0.8	0.6	3.0
2000	97.6	28.6	165.6	7.0	93.0	26.9	61.4	3.0	0.8	2.6
2001	97.8	36.7	172.2	5.4	94.6	28.4	61.9	1.8	0.8	2.0
2002	96.2	42.3	162.6	5.6	94.4	28.1	62.6	1.3	0.7	2.2
2003	98.2	42.6	178.1	5.1	94.9	28.3	63.2	1.2	0.7	1.9
2004	100.3	44.4	220.4	5.7	94.3	31.8	59.0	1.4	0.7	1.6

Source: National Agricultural Production Cost Survey (various years).

Table 9.D19. Yield, total cost, and major cost shares for special household egg production

Year	Yield	Output Per Man Day	Total Production Cost	Total Cost Share		Total Material Input Cost Share				
				Labor	Materials	Baby Animal	Fine Feed	Fodder	Feed Process	Depreciation
	(kg/per animal)	(kg)	(yuan/ton)	(percentage)		(percentage)				
1991	1256	13.9	2641.1	5.8	94.2	15.6	71.8	0.3	1.0	3.2
1992	1022	12.0	2484.9	6.4	93.6	16.8	68.5	3.2	0.5	3.3
1993	1226	19.3	2534.1	4.9	95.1	13.9	73.0	0.9	0.6	3.2
1994	1260	23.2	2501.0	4.5	95.5	10.4	80.0	0.2	0.5	2.4
1995	1350	31.0	2730.9	3.3	96.7	11.4	80.4	0.2	0.3	1.8
1996	1357	31.5	2390.1	4.6	95.4	9.3	82.6	0.8	0.5	1.6
1997	1448	39.9	2570.4	3.9	96.1	13.6	76.3	0.4	0.6	1.8
1998	1535	42.0	2454.3	4.5	95.5	13.9	79.5	0.2	0.7	1.5
1999	1463	50.5	2014.3	4.3	95.7	13.6	79.2	0.8	0.7	1.2
2000	1487	58.1	1962.6	3.9	96.1	20.5	73.3	0.2	0.7	1.4
2001	1545	60.4	2015.0	4.0	96.0	21.1	72.9	0.2	0.6	1.5
2002	1570	68.6	2055.3	3.8	96.2	19.6	73.7	0.1	0.6	1.7
2003	1551	68.6	2195.0	3.7	96.3	17.8	75.9	0.1	0.2	1.6
2004	1604	54.5	2360.7	4.9	95.1	20.5	75.3	0.0	0.3	0.9

Source: National Agricultural Production Cost Survey (various years).

Table 9.D20. Yield, total cost, and major cost shares for state-collective egg production

Year	Yield	Output Per Man Day	Total Production Cost	Total Cost Share		Total Material Input Cost Share				
				Labor	Materials	Baby Animal	Fine Feed	Fodder	Feed Process	Depreciation
	(kg/per animal)	(kg)	(yuan/ton)	(percentage)		(percentage)				
1991	1222	35.3	2637.0	2.2	97.8	19.9	64.8	0.6	0.4	4.6
1992	1256	33.2	3016.5	2.3	97.7	17.6	65.5	2.3	0.4	3.8
1993	1232	35.9	2856.5	2.4	97.6	12.5	73.7	0.1	1.2	2.8
1994	1426	36.2	3008.9	3.6	96.4	14.2	72.7	0.0	0.1	2.8
1995	1425	52.4	3228.5	2.5	97.5	12.7	76.7	1.2	0.2	2.0
1996	1481	58.8	3185.0	2.5	97.5	12.2	77.6	0.6	0.8	2.3
1997	1445	56.8	2716.6	3.3	96.7	15.3	73.8	0.1	1.1	2.4
1998	1469	58.3	2727.4	3.3	96.7	18.0	73.5	0.3	0.6	2.0
1999	1495	57.3	2318.0	4.3	95.7	20.4	70.5	0.0	0.6	2.7
2000	1523	77.3	2263.9	3.2	96.8	16.2	73.5	0.3	0.6	3.1
2001	1541	89.0	2273.8	3.1	96.9	19.0	72.5	0.0	0.5	2.7
2002	1581	114.6	2213.1	2.4	97.6	17.9	74.0	0.1	0.7	2.7
2003	1611	109.6	2437.6	2.5	97.5	18.4	73.4	0.0	1.0	2.6
2004	1600	95.4	2492.4	3.7	96.3	19.6	75.3	0.0	0.3	1.4

Source: National Agricultural Production Cost Survey (various years).

Table 9.D21. Yield, total cost, and major cost shares for beef cattle production

Year	Yield	Output Per Man Day	Total Production Cost	Total Cost Share: Labor	Total Cost Share: Materials	Total Material Input Cost Share: Baby Animal	Fine Feed	Fodder	Feed Process	Depreciation
	(kg/per animal)	(kg)	(yuan/ton)	(percentage)				(percentage)		
1985	218	2.8	528.1	22.6	77.4	55.4	15.9	0.0	0.0	0.0
1986	244	3.4	515.1	19.6	80.4	60.7	16.2	0.0	0.0	0.0
1987	256	4.6	489.5	20.7	79.3	66.7	16.5	0.0	0.0	0.0
1988	285	4.1	486.2	28.4	71.6	65.5	16.5	0.0	0.0	0.0
1989	297	5.9	395.5	20.7	79.3	64.5	16.4	11.0	0.6	3.9
1990	320	5.7	422.9	23.5	76.5	59.9	14.0	17.8	0.8	2.8
1991	366	7.7	484.0	16.7	83.3	73.6	11.1	10.9	0.5	1.7
1992	268	5.2	432.0	22.2	77.8	66.0	15.1	12.4	0.8	2.1
1993	330	6.9	429.0	22.1	77.9	65.3	14.3	11.4	1.2	3.2
1994	359	6.2	635.7	18.0	82.0	63.7	17.1	10.8	1.1	1.9
1995	370	7.6	553.6	17.3	82.7	50.4	25.6	11.0	1.1	3.2
1996	317	7.8	536.7	16.8	83.2	56.6	21.4	12.4	1.3	2.5
1997	360	10.2	451.4	20.0	80.0	61.1	18.6	11.0	1.5	3.1
1998	336	12.0	444.8	16.9	83.1	60.0	18.7	13.2	1.2	3.7
1999	356	11.5	514.8	16.4	83.6	63.5	16.5	8.9	0.8	2.3
2000	339	18.1	448.2	11.7	88.3	66.2	16.2	12.3	0.8	1.9
2001	350	15.3	463.3	13.5	86.5	66.6	18.5	10.0	0.8	1.6
2002	351	14.1	524.4	14.1	85.9	69.1	17.2	8.8	0.8	1.9
2003	379	12.4	592.0	15.7	84.3	69.0	18.2	7.7	0.7	2.0
2004	350	15.2	538.1	17.0	83.0	63.2	21.3	9.8	0.8	1.7

Source: National Agricultural Production Cost Survey (various years).

Table 9.D22. Yield, total cost, and major cost shares for special household milk production

Year	Yield	Output Per Man Day	Total Production Cost	Total Cost Share: Labor	Total Cost Share: Materials	Total Material Input Cost Share: Baby Animal	Fine Feed	Fodder	Feed Process	Depreciation
	(kg/per animal)	(kg)	(yuan/ton)	(percentage)				(percentage)		
1992	4335	42.2	1621.6	11.8	88.2	11.0	50.1	22.3	0.7	4.0
1993	4234	32.4	1700.0	15.1	84.9	10.7	54.2	20.5	1.5	2.5
1994	5159	48.5	1842.9	12.2	87.8	9.6	61.1	17.7	0.4	3.1
1995	4998	41.1	2039.5	11.5	88.5	7.2	64.9	19.3	0.4	1.8
1996	4705	64.9	1852.8	10.2	89.8	8.7	66.7	17.6	0.4	1.7
1997	5071	60.4	2344.2	10.3	89.7	6.8	50.2	22.5	0.6	4.5
1998	4602	65.7	1794.1	11.6	88.4	9.9	57.6	18.9	0.6	2.9
1999	4421	67.1	1690.6	11.0	89.0	8.3	62.7	15.9	0.8	3.5
2000	5032	64.4	1802.7	12.8	87.2	11.6	56.6	16.5	0.7	5.7
2001	5121	78.4	1910.1	10.7	89.3	11.6	58.9	16.5	0.4	5.0
2002	5226	68.4	2131.0	11.4	88.6	10.9	58.7	16.7	0.5	4.6
2003	5342	88.4	2120.0	10.0	90.0	11.8	58.8	18.0	0.4	4.0
2004	5159	109.6	2438.7	9.5	90.5	9.9	49.1	15.2	0.6	17.9

Source: National Agricultural Production Cost Survey (various years).

Table 9.D23. Yield, total cost, and major cost shares for state-collective milk production

Year	Yield	Output Per Man Day	Total Production Cost	Total Cost Share: Labor	Total Cost Share: Materials	Total Material Input Cost Share: Baby Animal	Fine Feed	Fodder	Feed Process	Depreciation
	(kg/per animal)	(kg)	(yuan/ton)	(percentage)				(percentage)		
1992	4744	35.9	2204.3	11.2	88.8	7.9	40.0	22.8	0.5	5.8
1993	4736	49.0	2233.9	8.5	91.5	6.8	45.8	23.0	0.2	4.5
1994	4477	47.8	2333.2	10.1	89.9	4.6	50.8	20.2	0.1	4.8
1995	4757	60.9	2711.0	8.2	91.8	6.5	52.4	20.0	0.2	5.0
1996	5139	55.1	3002.9	9.9	90.1	5.1	47.9	22.1	0.6	4.4
1997	5155	63.8	2775.7	9.3	90.7	5.0	47.2	23.8	0.8	5.2
1998	5435	86.9	2790.4	7.7	92.3	4.6	45.1	25.3	0.4	6.4
1999	5889	89.9	2890.0	8.2	91.8	7.9	43.1	26.2	0.5	6.4
2000	6019	92.9	3041.7	7.4	92.6	8.3	41.6	24.0	0.4	7.4
2001	6000	93.5	3006.4	6.7	93.3	6.4	44.2	25.1	0.4	8.7
2002	6032	93.7	3035.6	8.0	92.0	7.4	41.4	24.7	0.8	10.4
2003	6091	97.6	3227.0	7.6	92.4	7.5	44.1	24.3	0.6	8.8
2004	5868	139.0	3107.4	9.9	90.1	7.9	45.8	23.0	0.5	13.6

Source: National Agricultural Production Cost Survey (various years).

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CHAPTER 10

Shifting Patterns of Agricultural Production and Productivity in the Former Soviet Union and Central and Eastern Europe

Johan F.M. Swinnen, Kristine Van Herck, and Liesbet Vranken

1. INTRODUCTION

Economic and institutional reforms have dramatically affected the agricultural performance in all Central and Eastern European countries and Former Soviet Union republics. Not only did agricultural output fall dramatically in the region but also efficiency decreased during the transition, according to some studies.

In a review of the evidence, Rozelle and Swinnen (2004) found that despite the dramatic fall in agricultural output, agricultural productivity in Central Europe and parts of the Balkans and the Baltics started to increase in the early years of transition. Both labor productivity and total factor productivity sharply increased, whereas these productivity measures continued to decline much longer in most countries of the Former Soviet Union. Initial declines in productivity were associated with disruptions due to price liberalization and subsidy cuts (Macours and Swinnen 2000a), land reforms and farm restructur-

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ing (Macours and Swinnen 2000b), poor incentives and soft budget constraints in some countries of the Former Soviet Union (Sedik, Trueblood, and Arnade 1999), and the disruption of the previously vertically coordinated supply chain (Gow and Swinnen 1998).

Increases in both agricultural output and productivity are important for two reasons. First, higher production and productivity are crucial to meet the growing demand for food and nonfood agricultural products in both domestic and foreign markets (Coelli and Rao 2003). Second, an increase in output and productivity drives up agricultural incomes and improves the competitiveness of the sector (McMillan, Whalley, and Zhu 1989). In regions, such as the Former Soviet Union and some of the less economically advanced Central and Eastern European countries, where a considerable proportion of the rural population still depends on agriculture as its primary source of income, an increase in competitiveness is crucial to enhance the viability of the rural areas and reduce the poverty gap between urban and rural populations.

In this chapter we first analyze the evolution of agricultural output in the different Central and Eastern European countries and Former Soviet Union republics over the past two decades (Section 2).[1] Then we consider changes in input use (Section 3) and, by combining the information on changes in output and input use, we discuss the evolution of agricultural productivity in Section 4. In Section 5, we discuss the reform policies that caused the changes in agricultural output and productivity. Finally, in Section 6, we offer conclusions and draw some lessons on the links between policy and performance.

2. CHANGES IN AGRICULTURAL OUTPUT

The evolution of agricultural output is similar in all countries (Figure 10.1). In general, we observe an initial decline in agricultural output and a recovery later on. However, the magnitude of the decline and the length of time until

[1]To analyze the evolution of output and productivity, we classify the Central and Eastern European countries and the Former Soviet Union republics into six regions: Central and Eastern Europe consists of Central Europe and the Balkan countries, whereas the Former Soviet Union republics consist of the Baltic states, the European Commonwealth of Independent States (CIS), Transcaucasia, and Central Asia. Table 10.1 gives an overview of the classification of the different countries within the regions. Additionally, we refer to and compare input use, output, and productivity (changes) in four periods: the pre-reform period, early transition (year 1-5, roughly the first half of the 1990s), mid-transition (year 6-10, the second half of the 1990s), and the recent period (after 1999). In Central Europe and the Balkan countries, the start of the reforms is assumed to be the year 1989, while in the Baltic states, European CIS, Transcaucasia, and Central Asia the start is assumed to be 1990.

Table 10.1. Classification of the Central and Eastern European countries and the Former Soviet Union republics in different regions

Central Europe	Czech Republic Hungary Poland Slovakia	**Transcaucasia**	Armenia Azerbaijan Georgia
Balkans	Albania Bulgaria Romania Slovenia	**Central Asia**	Kazakhstan Kyrgyzstan Tajikistan Turkmenistan Uzbekistan
Baltics	Estonia Latvia Lithuania		
European CIS	Belarus Russia Ukraine		

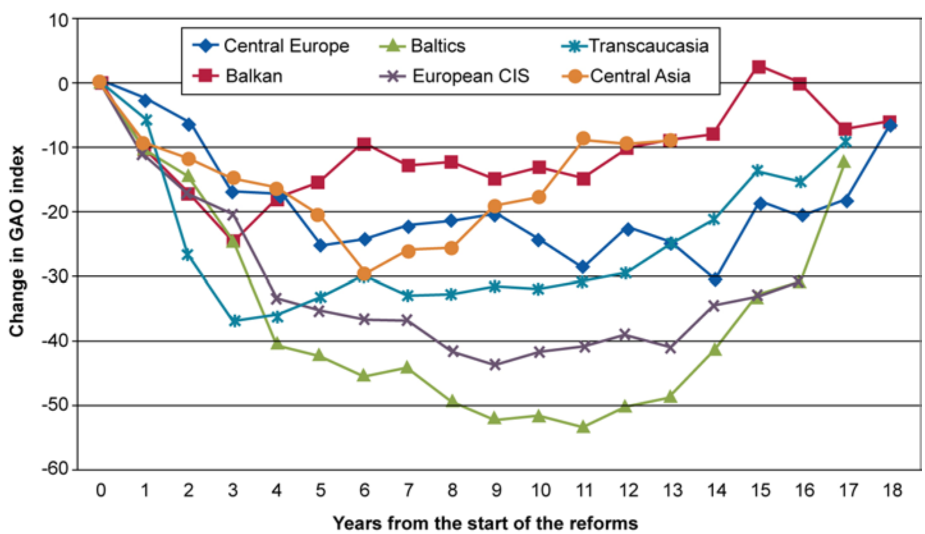

Figure 10.1. Evolution of gross agricultural output (GAO)

Sources: FAO (2008), Asian Development Bank (2008), Eurostat (2008).

Note: Reforms started in 1989 (=year 0) in Central Europe and the Balkan countries and in 1990 (=year 0) in the Baltic states, the European CIS, Transcaucasia, and Central Asia.

recovery differed significantly among regions and even among countries within regions (Table 10.2).

In the early transition period, gross agricultural output decreased in all regions by at least 20%. The transition from a centrally planned economy to a market-orientated economy coincided in all countries with subsidy cuts and price liberalization, which in general caused input prices to increase and output prices to decrease. Purchased inputs were no longer affordable at the new relative prices, and the decrease in input use caused a decrease in agricultural output. In the Baltic states and the European CIS, output decreased to about 50% to 60% of the pre-reform output. In Central Europe and Central Asia, output declined by 25% to 30%. Output stabilized in the mid-1990s in Central Europe and later also in the other regions. Currently, agricultural output is close to the pre-reform output level in most countries.

3. CHANGES IN INPUT USE

Changes in output and especially productivity are partly caused by changes in input use. Therefore we discuss in this section changes in the most important inputs, namely, labor, land, and capital.

3.1. Labor Use

In the Communist system, labor was inefficiently employed in most sectors of the economy, and several studies suggest that this was especially the case in agriculture (Brada 1989; Bofinger 1993; Jackman 1994). Consequently, the shift to a more efficient allocation of labor in the economy was expected to coincide with a re-allocation of agricultural labor and, more specifically, an outflow of labor from agriculture to other sectors.

This prediction did not totally coincide with the reality. In some regions, agricultural employment indeed dramatically declined in the early transition period (Figure 10.2). In Central Europe and the Baltic states, agricultural employment declined, respectively, by 40% and 20%. However, in other regions, such as the Balkan countries and the European CIS, agricultural employment was relatively stable, and it even increased in Transcaucasia and Central Asia. In these regions, agriculture is said to have provided a buffer role during transition, both in terms of labor allocation and in terms of food security (Seeth et al. 1998). By the end of the mid–transition period, agricultural employment in Transcaucasia had increased on average by almost 30% compared to the pre-reform period.

Table 10.2. Growth in gross agricultural output (GOA) (Index=100 in first year of reforms)

	GAO Index			Average Annual Growth Rate (% per year)		
	After 5 Years	After 10 Years	After 15 Years	Year 0-5	Year 5-10	Year 10-15
Central Europe						
Czech Republic	75	77	70	-5.0	0.5	-1.6
Hungary	70	73	82	-6.4	0.8	3.2
Poland	77	85	97	-4.9	2.2	3.2
Slovakia	77	68	76	-5.0	-2.3	3.0
Balkans						
Albania	100	113	133	0.7	2.9	3.2
Bulgaria	63	62	64	-8.4	0.1	1.2
Romania	93	93	116	-0.1	0.4	5.4
Slovenia	81	79	97	-3.0	-0.4	4.3
Baltics						
Estonia	55	42	58	-10.1	-5.1	6.8
Latvia	50	38	55	-12.4	-4.5	7.7
Lithuania	69	65	89	-6.8	-1.0	6.8
European CIS						
Belarus	61	58	71	-8.8	-1.2	4.5
Russia	64	62	70	-8.5	-0.3	2.5
Ukraine	69	55	58	-7.1	-4.0	1.5
Transcaucasia						
Armenia	82	80	100	-3.3	-0.3	4.8
Azerbaijan	55	72	94	-10.9	5.7	5.4
Georgia	62	51	66	-8.2	-3.4	6.0
Central Asia						
Kazakhstan	53	52	55	-10.5	1.1	1.2
Kyrgyzstan	79	110	109	-4.6	6.9	-0.1
Tajikistan	61	53	n.a.	-9.0	-2.6	2.0
Turkmenistan	106	99	151	1.4	0.8	9.6
Uzbekistan	98	97	125	-0.3	-0.2	5.4

Source: FAO 2008.
Note: Reforms started in 1989 in Central Europe and the Balkan countries and in 1990 in the Baltic states, the European CIS, Transcaucasia, and Central Asia.

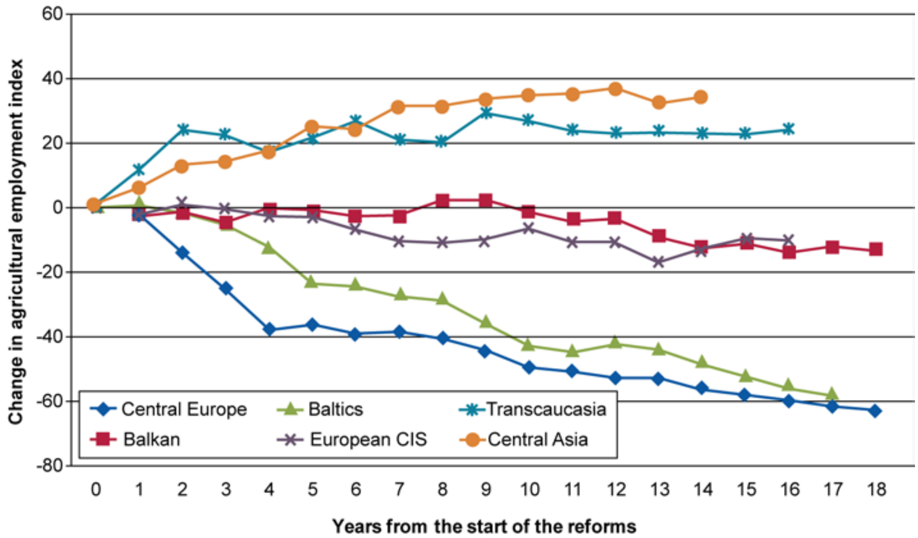

Figure 10.2. Evolution of agricultural employment
Sources: Asian Development Bank 2008, Eurostat 2008, ILO 2008.
Note: Reforms started in 1989 (=year 0) in Central Europe and the Balkan countries and in 1990 (=year 0) in the Baltic states, the European CIS, Transcaucasia, and Central Asia.

Also among countries, agricultural employment evolved differently (Table 10.3). In the Czech Republic and Slovakia, agricultural employment declined in the early transition period on average by, respectively, 11% per year and 6% per year, whereas in Poland the decline was only 2% per year in the same period.

A similar pattern to that of Poland is found in some Balkan countries, such as Romania and Bulgaria. In these countries, agricultural employment initially increased, as rural labor was absorbed by the agricultural sector. However, from 2000 on, the reduction of the agricultural labor force became a constant element in all countries in Central Europe, the Balkans, and the Baltic states.

In the European CIS, Transcaucasia, and Central Asia, the pattern is rather mixed. In Belarus, Georgia, and Kazakhstan, agricultural employment started to decline immediately after the start of the reforms and continued to decline in the mid-transition and recent periods. In most other countries in Transcaucasia, Central Asia, and the European CIS, the agricultural sector absorbed surplus labor in the early transition period, but unlike in Poland and the Balkan countries, there is no strong decrease in agricultural employment observed in the mid–transition period. In some countries in Central Asia, such as Kyrgyzstan, Tajikistan, and Turkmenistan, agricultural employment increased even further in

Table 10.3. Growth in agricultural employment (Index=100 in first year of reforms)

	Labor Use Index			Average Annual Growth Rate (% per year)		
	After 5 Years	After 10 Years	After 15 Years	Year 0-5	Year 5-10	Year 10-15
Central Europe						
Czech Republic	54	39	32	-11.10	-6.27	-3.90
Hungary	43	35	27	-15.26	-3.68	-5.33
Poland	89	83	77	-2.19	-1.30	-1.40
Slovakia	71	47	33	-6.22	-7.74	-6.81
Balkan						
Albania	92	92	93	-0.83	-0.09	0.21
Bulgaria	92	95	96	-1.45	0.72	0.24
Romania	118	115	78	3.44	-0.39	-7.27
Slovenia	95	93	89	-0.77	0.19	-0.22
Baltics						
Estonia	40	27	21	-16.37	-6.99	-5.00
Latvia	79	56	51	-4.47	-6.20	-1.63
Lithuania	113	89	70	2.59	-4.55	-4.26
European CIS						
Belarus	86	67	54	-2.99	-4.68	-4.19
Russia	100	113	92	0.08	2.75	-3.80
Ukraine	106	100	123	1.33	-1.10	4.43
Transcaucasia						
Armenia	194	179	174	14.96	-1.44	-0.62
Azerbaijan	97	137	136	-0.38	8.11	-0.07
Georgia	74	65	58	-5.76	-2.72	-1.96
Central Asia						
Kazakhstan	89	n.a.	n.a.	-2.24	n.a.	n.a.
Kyrgyzstan	135	164	140	6.36	4.06	-2.99
Tajikistan	131	134	155	5.65	0.66	2.92
Turkmenistan	121	140	157[a]	3.92	2.96	2.88
Uzbekistan	112	99	91	2.35	-2.33	-1.70

Sources: Asian Development Bank 2008, Eurostat 2008, and ILO 2008.
Note: Reforms started in 1989 in Central Europe and the Balkan countries and in 1990 in the Baltic states, the European CIS, Transcaucasia, and Central Asia.
[a]After 14 years of reform.

the mid–transition period. In the recent period, agricultural employment started to decrease in most countries in Transcaucasia, Central Asia, and the European CIS. However, in some countries, such as Tajikistan and Turkmenistan, agricultural employment is still increasing.

3.2. Land Use

The evolution of land use was different among regions (Table 10.4). In Central Europe, the Balkan countries, the Baltic states, and the European CIS, agricultural land use was relatively stable in the early transition period. In the same period, land use in Transcaucasia and Central Asia decreased by, respectively, 6% and 10%. After this decrease, agricultural land use stabilized, and in Transcaucasia agricultural land use recently reached the pre-reform land-use level.

3.3. Capital Use

The most dramatic changes in input use in the first years after transition were changes in capital use. In this section we discuss changes in tractor and fertilizer use.

The evolution of tractor use in the different countries is shown in Table 10.5. In the early transition period, tractor use in Central Europe declined by 17%, and in the Balkan countries the decline was even larger, namely, 24% compared to the pre-reform level. In the subsequent periods tractor use stabilized, and in some countries it even increased. In the European CIS, Transcaucasia, and Central Asia, tractor use initially declined less compared to use in Central Europe and the Balkan countries. However, in the subsequent years, the decline in tractor use accelerated, and, for example, after 15 years of transition, tractor use in the European CIS reached only 50% of the pre-reform level.

Fertilizer use declined even more dramatically than tractor use, although the pattern of decline in the different regions is similar (Table 10.6). In Central Europe and the Baltic states, fertilizer use declined in the early transition period by almost 80%, and in the Balkan countries, it declined by 65%. In the European CIS, Transcaucasia, and Central Asia, fertilizer use also declined in the first four years of transition, but in the succeeding years the decline accelerated, and by 2002 fertilizer use fell to approximately 20% of pre-reform fertilizer use. In some countries, such as Kazakhstan, Armenia, or Russia, it declined to less than 10% of pre-reform fertilizer use.

Table 10.4. Growth in land use (Index=100 in first year of reforms)

	Land Use Index			Average Annual Growth Rate (% per year)		
	After 5 Years	After 10 Years	After 15 Years	Year 0-5	Year 5-10	Year 10-15
Central Europe						
Czech Republic	103	103	103	0.67	0.03	-0.08
Hungary	94	95	90	-1.12	0.21	-1.04
Poland	99	98	87	-0.12	-0.29	-2.34
Slovakia	100	100	86	-0.03	-0.02	-2.74
Balkan						
Albania	101	103	101	0.29	0.34	-0.40
Bulgaria	100	105	110	0.05	0.98	0.93
Romania	100	100	96	0.05	-0.02	-0.88
Slovenia	91	83	82	-1.84	-1.82	-0.29
Baltics						
Estonia	107	107	90	1.49	-0.07	-2.27
Latvia	99	97	106	-0.18	-0.45	1.77
Lithuania	100	100	111	0.01	-0.11	2.25
European CIS						
Belarus	98	97	93	-0.48	-0.19	-0.88
Russia	98	99	98	-0.34	0.07	-0.14
Ukraine	100	99	98	-0.08	-0.21	-0.05
Transcaucasia						
Armenia	102	108	116	-2.90	1.17	1.45
Azerbaijan	96	103	106	-0.73	1.39	0.63
Georgia	86	85	71	-0.14	-0.31	-3.22
Central Asia						
Kazakhstan	96	93	93	-2.90	-0.70	0.10
Kyrgyzstan	99	102	102	-0.73	0.46	0.09
Tajikistan	97	94	94	-0.14	-0.67	-0.11
Turkmenistan	73	74	75	-0.52	0.14	0.26
Uzbekistan	89	89	87	-5.78	-0.01	-0.34

Source: FAO 2008

Note: Reforms started in 1989 in Central Europe and the Balkan countries and in 1990 in the Baltic states, the European CIS, Transcaucasia, and Central Asia.

Table 10.5. Growth in tractor use (Index=100 in first year of reforms)

	Tractor Use Index			Average Annual Growth Rate (% per year)		
	After 5 Years	After 10 Years	After 15 Years	Year 0-5	Year 5-10	Year 10-15
Central Europe						
Czech Republic	58	71	80	-6.34	-2.02	-1.96
Hungary	72	72	86	2.75	0.03	-0.51
Poland	114	113	118	-2.22	-0.26	1.12
Slovakia	89	65	60	-5.26	-3.65	-1.52
Balkan						
Albania	74	67	62	-6.86	-2.05	-1.67
Bulgaria	69	75	58	1.55	1.65	-2.13
Romania	106	108	113	-9.97	0.08	1.80
Slovenia	56	72	69	1.13	5.8	-1.66
Baltics						
Estonia	106	108	119	-3.77	0.11	0.02
Latvia	82	91	91	3.48	-2.84	0.21
Lithuania	118	138	169	-1.58	2.83	5.31
European CIS						
Belarus	92	58	44[a]	-3.94	-7.97	-29.66
Russia	82	58	37	-1.68	-6.21	-8.93
Ukraine	92	62	69	3.62	-7.82	-3.93
Transcaucasia						
Armenia	119	117	128	-1.92	0.27	0.22
Azerbaijan	90	91	52	-6.54	-1.08	-10.70
Georgia	71	73	64	-4.64	4.00	-1.48
Central Asia						
Kazakhstan	78	23	21	-0.04	-22.19	-2.96
Kyrgyzstan	99	102	88[b]	-3.21	6.93	-3.71
Tajikistan	84	65	59	-4.21	-5.13	-0.42
Turkmenistan	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Uzbekistan	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

Source: FAO 2008.

Note: Reforms started in 1989 in Central Europe and the Balkan countries and in 1990 in the Baltic states, the European CIS, Transcaucasia and Central Asia.

[a]After 14 years of reform.

[b]After 13 years of reform.

Table 10.6. Growth in fertilizer use (Index=100 in first year of reforms)

	Fertilizer Use Index			Average Annual Growth Rate (% per year)		
	After 4 Years	After 8 Years	After 12 Years	Year 0-4	Year 4-8	Year 8-12
Central Europe						
Czech Republic	27	27	35	-26.6	1.0	6.9
Hungary	13	20	21	-36.3	12.9	2.2
Poland	33	42	39	-21.7	6.4	-1.8
Slovakia	16	18	20	-33.7	3.4	4.5
Balkan						
Albania	25	7	23	-21.6	-27.9	99.9
Bulgaria	26	22	22	-27.1	2.7	3.2
Romania	29	23	27	-22.7	-4.9	7.5
Slovenia	61	49	48	-11.5	-4.6	-0.5
Baltics						
Estonia	27	20	16	n.a.	-3.8	-2.9
Latvia	21	48	48	-29.0	23.6	2.4
Lithuania	16	12	17	-32.6	-4.5	8.8
European CIS						
Belarus	34	44	35	-21.5	9.7	-5.0
Russia	30	8	9	-24.4	-23.1	4.2
Ukraine	29	14	16	-24.7	-14.5	4.7
Transcaucasia						
Armenia	23	15	17	-30.4	-4.7	18.7
Azerbaijan	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Georgia	39	24	20	-20.1	-8.0	-2.3
Central Asia						
Kazakhstan	42	2	11	-18.9	-39.7	59.1
Kyrgyzstan	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Tajikistan	32	16	12	n.a.	-16.2	19.8
Turkmenistan	51	23	30	n.a.	-11.4	7.1
Uzbekistan	46	59	52	-17.7	14.8	-3.4

Source: FAO 2008.

Note: Reforms started in 1989 in Central Europe and the Balkan countries and in 1990 in the Baltic states, the European CIS, Transcaucasia, and Central Asia.

4. CHANGES IN AGRICULTURAL PRODUCTIVITY

Total factor productivity (TFP) is often calculated using index number methods described in the growth accounting literature. Typically, these measures account for growth in output by measuring the impact of changes in input quantities. The unexplained residual, which is called TFP, measures changes in total output not accounted for by changes in inputs.

For the agricultural sector in the Central and Eastern European countries and the Former Soviet Union republics, TFP estimates are limited. Macours and Swinnen (2000b) estimated TFP for the Central and Eastern European countries for the period 1989-1995. Swinnen and Vranken (2009) extended this series to 2002. Lerman, Csaki, and Feder (2004) estimated TFP indices for the Former Soviet Union republics. Other studies on a wide variety of countries performed farm-level productivity analyses based on farm survey data (see Gorton and Davidova 2004 for a review).

Given the limited TFP estimates, we first discuss partial productivity estimates, such as labor productivity, land productivity, and output per livestock unit. Then we discuss the available TFP studies in the region, and although only limited TFP comparisons can be made between countries and over time, the available evidence on TFP is roughly consistent with the evidence from the partial productivity indicators.

4.1. Partial Factor Productivity

4.1.1. Labor Productivity

A first partial measure of productivity that we consider is agricultural labor productivity (ALP), measured as output per farm worker (Figure 10.3). Despite a decrease in agricultural output in total, output per worker in Central Europe strongly increased during the past two decades. This increase was driven by the dramatic decrease in agricultural employment in the early transition period. As output stabilized at the end of the mid–transition period and agricultural employment continued to decline, the increase in ALP continued.

However, this was not the pattern followed by all countries in Central Europe (Table 10.7). In Poland, the agricultural sector acted as a social buffer and absorbed rural labor in the early transition period (Swinnen, Dries, and Macours 2005). ALP decreased initially, as much labor was absorbed in agriculture. In the mid–transition period, outflow of agricultural labor started, and ALP began to increase.

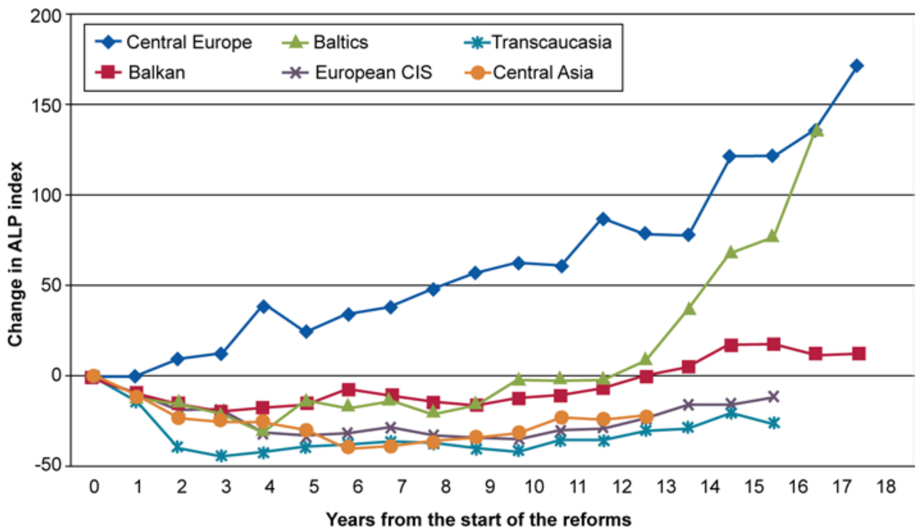

Figure 10.3. Evolution of agricultural labor productivity (ALP)
Sources: FAO 2008, Asian Development Bank 2008, Eurostat 2008, ILO 2008.
Note: Reforms started in 1989 (=year 0) in Central Europe and the Balkan countries and in 1990 (=year 0) in the Baltic states, the European CIS, Transcaucasia, and Central Asia.

A similar pattern to that of Poland is found in some Balkan countries, such as Romania and Bulgaria. Initially, ALP decreased, as rural labor was absorbed by the agricultural sector. However, in the late 1990s, labor began to flow out from agriculture, and this outflow of labor, in combination with increased investments in the farming and agri-food industry, resulted in a gradual but consistent improvement in ALP.

Farther east, ALP strongly decreased in the first decade after transition. On average, ALP decreased by 33% in the European CIS and by 30% in Central Asia in the early transition period. The strong decline in ALP was the result of two effects. First, agricultural output declined strongly in both regions, and second, the outflow of agricultural labor was limited and in some regions agricultural employment even increased. In the mid–transition period, however, the decline in ALP started to slow down, and since the beginning of 2000, ALP has recovered slowly.

4.1.2. Land Productivity

A second partial productivity measure is land productivity or yield. Figure 10.4 gives the evolution of the average yield in the different regions. In all

Table 10.7. Growth in agricultural labor productivity (ALP) (Index=100 in first year of reforms)

	ALP index			Average Annual Growth Rate (% per year)		
	After 5 Years	After 10 Years	After 15 Years	Year 0-5	Year 5-10	Year 10-15
Central Europe						
Czech Republic	140	198	222	9.06	7.30	2.56
Hungary	164	207	307	10.84	4.78	9.18
Poland	86	102	126	-2.66	3.80	4.67
Slovakia	110	145	230	2.26	5.83	10.88
Balkan						
Albania	108	124	143	3.31	2.89	3.02
Bulgaria	69	64	67	-6.90	-0.53	1.04
Romania	79	81	157	-3.34	1.06	15.55
Slovenia	85	85	110	-1.51	0.55	5.73
Baltics						
Estonia	138	153	274	10.18	2.47	12.96
Latvia	64	68	107	-8.38	2.22	9.97
Lithuania	61	73	126	-8.88	3.87	12.30
European CIS						
Belarus	72	85	132	-5.79	3.75	9.19
Russia	63	55	76	-8.50	-2.45	6.91
Ukraine	65	55	47	-8.34	-2.93	-2.94
Transcaucasia						
Armenia	42	45	57	-14.34	1.25	5.39
Azerbaijan	57	53	69	-9.99	-0.78	5.50
Georgia	84	79	113	-2.60	-0.73	8.10
Central Asia						
Kazakhstan	60	n.a.	n.a.	-8.23	n.a.	n.a.
Kyrgyzstan	58	67	78	-9.98	2.88	3.43
Tajikistan	46	39	40[a]	n.a.	-2.95	1.01[a]
Turkmenistan	88	71	84[b]	-2.40	-2.00	5.42[b]
Uzbekistan	88	98	138	-2.33	2.31	7.22

Sources: FAO 2008, Asian Development Bank 2008, Eurostat 2008.
Note: Reforms started in 1989 in Central Europe and the Balkan countries and in 1990 in the Baltic states, the European CIS, Transcaucasia, and Central Asia.
[a]After 13 years of reform.
[b]After 14 years of reform.

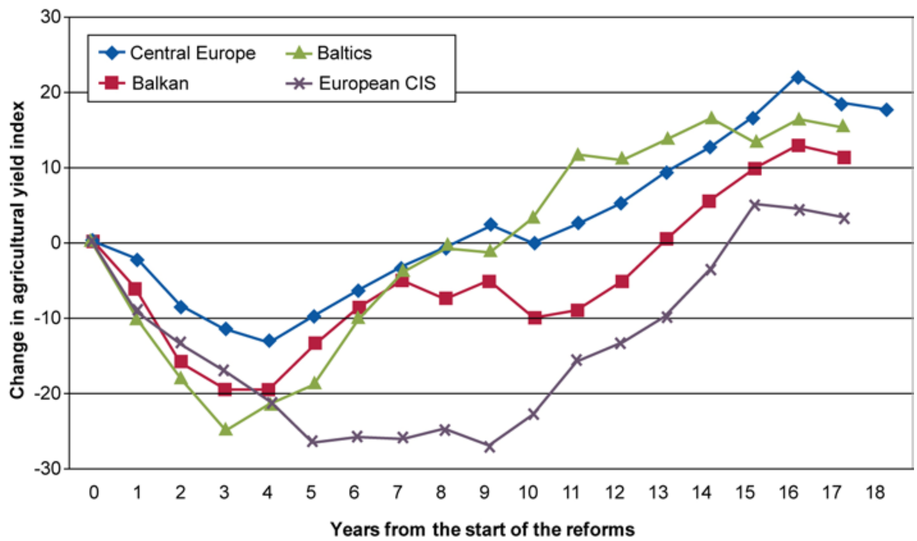

Figure 10.4. Evolution of average agricultural yield
Source: FAO 2008.
Notes: Average yield is the average yield index of milk, grains and sugar beet. Calculations are based on the average of the milk yield, a three-year moving average of the grain yield, and a three-year moving average of the sugar beet yield. Balkan does not include Slovenia. Reforms started in 1989 (=year 0) in Central Europe and the Balkan countries and in 1990 (=year 0) in the Baltic states, the European CIS, Transcaucasia, and Central Asia.

regions, average yield fell in the early transition period and recovered later. However, the depth and the length of the decrease differed strongly among countries. Average yields recovered considerably in the mid–transition period in countries such as Hungary, nations with relatively more large-scale farming and investments in the food industry. In contrast, average yield grew more slowly and more modestly in countries such as Romania, which has a large number of small-scale family farms with difficult access to inputs. Average yield declined the most in the European CIS and Central Asia, where yields started to increase from the beginning of 2000, and only recently have yields reached their pre-reform levels.

The aggregate figures on the evolution of the average yield in the different regions hide important differences among commodities. Therefore, we consider average grain yield and its evolution in the different regions and countries. In addition, we also analyze sugar beet yields in Central Europe, the Balkan countries, the Baltic states, and the European CIS, as well as and cotton yields in Central Asia (Table 10.8 and Table 10.9).

Table 10.8. Average grain, sugar beet, and cotton yields in 2005-2007

	Barley (tons/ha)	Corn (tons/ha)	Wheat (tons/ha)	Sugar Beet (tons/ha)	Cotton (tons/ha)
Central Europe					
Czech Republic	3.87	6.91	4.80	52.68	-
Hungary	3.55	7.03	4.06	50.18	-
Poland	3.02	5.49	3.71	45.56	-
Slovakia	3.41	5.50	3.99	48.84	-
Balkan					
Albania	2.66	4.74	3.26	21.67	-
Bulgaria	2.56	3.77	2.92	17.18	-
Romania	2.07	3.09	2.46	28.31	-
Slovenia	3.75	7.60	4.35	42.56	-
Baltics					
Estonia	2.50	n.a.	3.03	n.a.	-
Latvia	2.29	n.a.	3.32	37.28	-
Lithuania	2.44	3.41	3.34	41.40	-
European CIS					
Belarus	2.87	4.33	3.13	35.98	-
Russia	1.86	3.48	2.00	29.99	-
Ukraine	1.90	3.98	2.57	27.57	-
Central Asia					
Kazakhstan	1.18	4.45	1.13	-	2.22
Kyrgyzstan	1.96	6.06	2.10	-	2.64
Tajikistan	1.60	3.94	2.10	-	1.64
Turkmenistan	1.05	1.07	3.29	-	1.44
Uzbekistan	1.52	5.88	4.30	-	2.53

Source: FAO 2008.

Change in grain productivity. In the early transition period, grain yield decreased by more than 20% in all regions (Figure 10.5). After five years, grain yield started to recover in all countries, except in the European CIS, where yield remained for the next decade at approximately 75% of the pre-reform yield.

There are large differences in yields among countries (Table 10.8). Yields of arable crop production are the highest in the Central European countries and the lowest in the European CIS and Central Asia, reflecting differences in productivity and soil quality.

Changes in yields of sugar beet and cotton. In Central Europe and the Baltic states, sugar beet yield decreased by 10% and 20%, respectively (Figure 10.6). In the mid–transition period, yield started to gradually increase, and in 2005 sugar

Table 10.9. Growth in land productivity (Index=100 in first year of reforms)

	Grain Yield Index			Sugar Beet Yield Index			Cotton Yield Index		
Years after the Reforms	**5**	**10**	**15**	**5**	**10**	**15**	**5**	**10**	**15**
Central Europe									
Czech Republic	86	85	97	110	126	140	-	-	-
Hungary	69	71	87	67	91	107	-	-	-
Poland	86	89	100	101	109	123	-	-	-
Slovakia	84	75	84	99	103	131	-	-	-
Balkan									
Albania	86	90	104	62	77	78	-	-	-
Bulgaria	62	62	69	55	57	90	-	-	-
Romania	88	92	101	75	70	98	-	-	-
Baltics									
Estonia	75	84	100	89	n.a.	n.a.	-	-	-
Latvia	82	93	102	79	107	126	-	-	-
Lithuania	66	84	89	83	109	130	-	-	-
European CIS									
Belarus	79	68	87	65	84	110	-	-	-
Russia	70	79	95	69	86	131	-	-	-
Ukraine	67	62	73	83	74	110	-	-	-
Central Asia									
Kazakhstan	54	93	76	-	-	-	69	74	83
Kyrgyzstan	63	93	99	-	-	-	74	111	124
Tajikistan	81	101	150	-	-	-	51	57	67
Turkmenistan	76	70	123	-	-	-	72	58	53
Uzbekistan	98	55	228	-	-	-	90	82	95

Source: FAO 2008.

Notes: Calculations are based on a three-year moving average of grain yield, a three-year moving average of sugar beet yield, and a three-year moving average of cotton yield. Reforms started in 1989 in Central Europe and the Balkan countries and in 1990 in the Baltic states, the European CIS, Transcaucasia, and Central Asia.

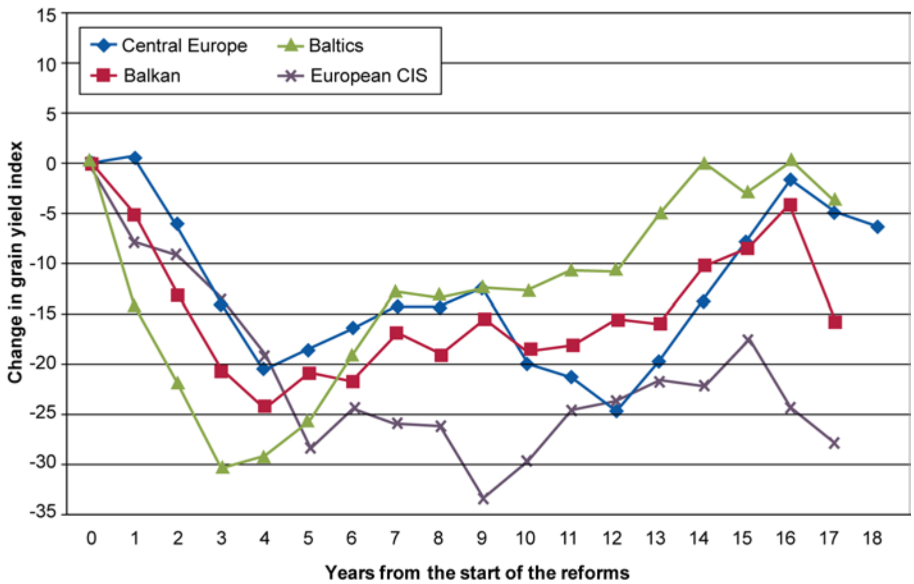

Figure 10.5. Evolution of grain yield
Source: FAO 2008.
Notes: Calculations based on three-year moving average of the grain yield. Balkan does not include Slovenia. Reforms started in 1989 (=year 0) in Central Europe and the Balkan countries and in 1990 (= year 0) in the Baltic states, the European CIS, Transcaucasia, and Central Asia.

beet yield increased by 30% compared to the pre-reform level. In the Balkan countries, sugar beet yield declined by almost 40% in the first years of transition, and also in the mid–transition period yields were substantially below the pre-reform level. Recently, sugar beet yields gradually increased, and in 2005 yield reached the pre-reform level. The evolution of sugar beet yield in the European CIS followed a similar pattern as in the Balkan countries until the beginning of the 2000s. From then on, yield increased very strongly, and by 2005 yield had increased by almost 20% compared to the pre-reform period.

In Central Asia, cotton yield decreased by 30% compared to the pre-reform period, and after a slight increase in the beginning of the 2000s, yield stabilized at 85% of the pre-reform cotton yield.

4.1.3. Output per Livestock Unit

Except for the Balkan countries, milk yield initially declined in all regions (Figure 10.7). Yield reached a minimum for Central Europe and the Baltic states at, respectively, 90% in 1992 and 80% in 1993 of the pre-reform milk yield.

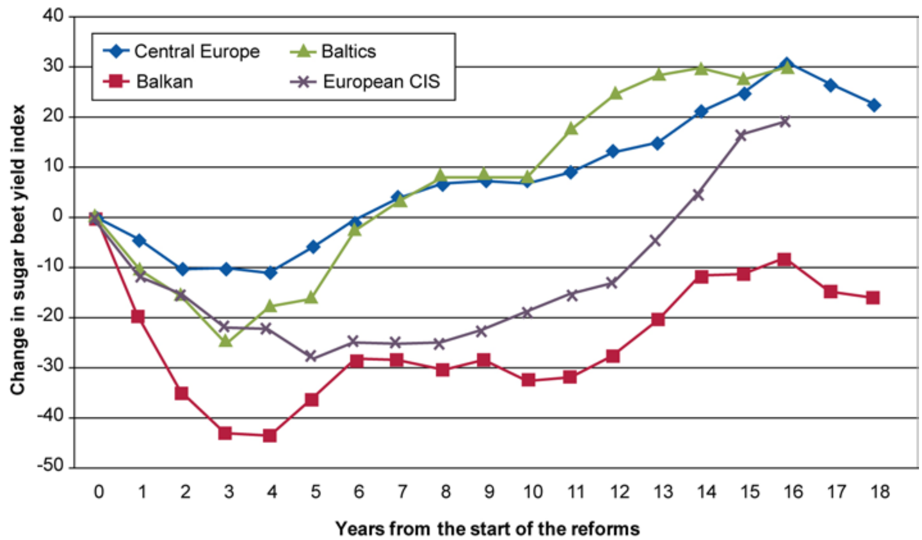

Figure 10.6. Evolution of sugar beet yield

Source: FAO 2008.

Notes: Calculations based on three-year moving average of the sugar beet yield for Central Europe, the Balkan countries, the Baltic states, and the European CIS. Reforms started in 1989 (=year 0) in Central Europe and the Balkan countries and in 1990 (= year 0) in the Baltic states, the European CIS, Transcaucasia, and Central Asia.

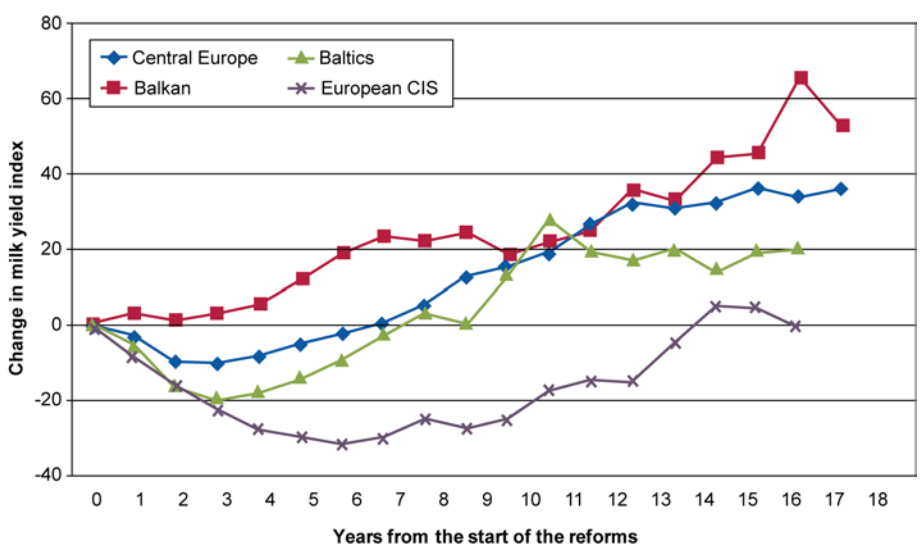

Figure 10.7. Evolution of milk yield

Source: FAO 2008.

Notes: Balkan does not include Slovenia. Reforms started in 1989 (= year 0) in Central Europe and the Balkan countries and in 1990 (= year 0) in the Baltic states, the European CIS, Transcaucasia, and Central Asia.

From then on, milk yield in both regions steadily increased, to 136% and 120% respectively in 2007. Productivity fell farthest in the European CIS and continued to decrease when productivity in all other regions started to recover. In the mid–transition period, milk yield in the European CIS slowly began to recover after it had decreased to less than 68% of the pre-reform milk yield, and in 2005, milk yield reached the pre-reform level.

Milk yield is highest in the Central European and Baltic countries where the average yearly milk yield is between 4 and 7 tons per livestock unit (Table 10.10). In the Balkan and European CIS, milk yield is between 2 and 3 tons per livestock unit per year, whereas in Central Asia milk yield is very low. In Tajikistan, milk yield is below 1 ton per livestock unit per year.

4.2. Total Factor Productivity (TFP)

4.2.1. Evolution in TFP in Central Europe and the Balkan countries, 1989-2002

Macours and Swinnen (2000b) and Swinnen and Vranken (2009) estimated TFP for the four Central European countries and the four Balkan countries based on crop production (Table 10.11).

Table 10.10. Output per livestock unit in 2007

	Milk production (tons/animal/year)		Milk production (tons/animal/year)
Central Europe		**European CIS**	3.90
Czech Republic	6.72	Belarus	3.50
Hungary	6.88	Russia	3.66
Poland	4.44	Ukraine	
Slovakia	5.81		
		Central Asia	2.20
Balkan		Kazakhstan	2.05
Albania	2.28	Kyrgyzstan	0.72
Bulgaria	3.28	Tajikistan	1.37
Romania	3.39	Turkmenistan	1.70
		Uzbekistan	
Baltics			
Estonia	6.38		
Latvia	4.60		
Lithuania	4.84		

Source: FAO 2008.

Table 10.11. Growth in TFP in Central Europe and the Balkans (% per year)

	Average annual change 1989-2001	Average annual change 1989-1992	Average annual change 1992-1995	Average annual change 1995-1998	Average annual change 1998-2001
Overall	**1.6**	**-1.9**	**4.9**	**1.4**	**2.0**
Central Europe	**2.1**	**0.4**	**2.2**	**4.2**	**1.7**
Czech	1.4	1.3	2.3	3.9	-1.5
Hungary	4.0	1.9	3.4	5.1	5.6
Poland	0.8	-1.7	0.5	3.3	0.9
Slovakia	2.2	0.1	2.4	4.3	2.1
Balkan	**1.1**	**-4.1**	**7.5**	**-1.3**	**2.3**
Albania	2.6	-1.1	5.6	2.1	3.9
Bulgaria	-0.4	-1.3	4	-4.1	-0.2
Romania	2.5	-4.2	11.6	-4.8	7.5
Slovenia	-0.4	-9.9	9.0	1.6	-2.2

Source: Swinnen and Vranken 2009.

In Central Europe, TFP grew slightly in the first years of transition—0.4% annually between 1989 and 1992—and significantly afterward—by 2.2% annually between 1992 and 1995 and by 4.4% annually between 1995 and 1998. Studies find a slowdown of TFP growth in the period 1998-2001. The slowdown was probably due to substantial investments in agricultural machinery and capital inputs in this period (Swinnen and Vranken 2009).

In the Balkan countries, the TFP evolution fluctuated much more. TFP decreased strongly, by 4.1% per year, from 1989 to 1992. Later TFP recovered more strongly when it increased by 7.5% per year in the period 1992-1995, but it fell again in the late 1990s, with bad macro-economic policies resulting in TFP declines of 1.3% annually from 1995 to 1998. After 1998 when a series of important reforms were implemented in the region, there was a strong recovery in productivity—from 1998 to 2001, TFP grew on average by 2.3% per year.

The TFP numbers of Albania and Slovenia are remarkable (Swinnen and Vranken 2009). Although Slovenia was one of the richest Balkan countries, its average annual growth rate of TFP was negative for the period 1989-2001. This is in contrast with Albania. Albania was one of the poorest Balkan countries after the fall of the Berlin Wall. However, despite a small decline in TFP in the period 1989-1992, TFP strongly increased beginning in 1992, reflecting successful land reforms and farm restructuring.

4.2.2. Evolution in TFP in the other Former Soviet Union republics

Few TFP estimates have been published for the Former Soviet Union republics. The only study that allows some comparison among all Former Soviet Union republics is by Lerman, Csaki, and Feder (2004) (Table 10.12). They showed that in two Baltic states, Estonia and Lithuania, and two Transcaucasian countries, Armenia and Georgia, TFP strongly increased. In the Central Asian countries, TFP growth was negative.

More work has been done on TFP estimates in Russia and Ukraine; however, the results are less consistent. In these countries, Lerman, Csaki, and Feder (2004) found an increase in TFP during 1992-1997, while partial measures of productivity decreased. In the same period, other studies found a decrease in TFP in both countries (Sedik, Trueblood, and Arnade 1999; Trueblood and Osborne 2001; Kurkalova and Jensen 2003).

5. SOURCES OF CHANGES IN OUTPUT AND PRODUCTIVITY

Several studies have tried to explain changes in output and productivity that occurred after the reforms. In general, post-reform changes in output and productivity are related to the choice of the reform instruments (Roland 1997; Aslund,

Table 10.12. Growth in TFP in the Baltic states, the European CIS, Transcaucasia, and Central Asia (% per year)

	Average annual change 1992-1997		Average annual change 1992-1997
Overall	0.4		
Baltics	**1.7**	**Central Asia**	**-2.4**
Estonia	2,8	Kazakhstan	-1.0
Latvia	-1.2	Kyrgyzstan	-0.4
Lithuania	3.6	Tajikistan	-2.4
		Turkmenistan	-5.8
European CIS	**0.8**	Uzbekistan	-2.2
Belarus	0.6		
Russia	1.4		
Ukraine	0.4		
Transcaucasia	**3.5**		
Armenia	4.6		
Azerbaijan	-0.8		
Georgia	6.6		

Source: Lerman, Csaki, and Feder 2004.

Boone, and Johnson 1996), the pre-reform economic conditions (Sachs and Woo 1994; Woo 1994; Macours and Swinnen 2002), the disruption of previously vertically coordinated supply chains (Blanchard 1997; Gow and Swinnen 1998), the inflow of foreign direct investments in the agri-food industry restructuring (Gow, Streeter, and Swinnen 2000; Dries and Swinnen 2004), and regional tensions and conflict (de Melo and Gelb 1996). Other authors, such as Jackson and Swinnen (1994), also mention the importance of the statistical bias that is caused by over-reporting of the effective output in the pre-reform period and underestimation of the actual output because of limited statistical coverage after the reforms.

In this section we discuss the most important factors that have affected agricultural output and productivity in the past few decades. First, we analyze the role of the initial conditions and the institutional framework. Second, we discuss the role of price liberalization and subsidy cuts. Third, we consider privatization and land reform. Fourth, we analyze the role of farm restructuring. And finally, we analyze a more recent evolution, the inflow of foreign direct investments and the introduction of vertically coordinated supply chains.

5.1. Initial Conditions and Institutional Framework

At the start of the transition, there were substantial differences among regions and even countries in the performance of the overall economy, the importance of the agricultural sector in the overall economy, the technology used in the agricultural sector, and the number of years under central planning (Table 10.13).

The initial conditions affected the transition in two important ways. On the one hand, they affected the impact of reform policies; on the other hand, through institutional and political constraints, they affected the choice of the reform policy. For example, the collectivization of agriculture and the introduction of central planning occurred in the 1920s in the Former Soviet Union but only after World War II in Central Europe and the Balkan countries. Consequently, rural households in Central Europe and the Balkan countries had much more experience with private farming than their counterparts in most of the Former Soviet Union. This difference affected not only the emergence and dynamics of the new private farms but also the preferences for land reforms: in Central Europe and the Balkan households wanted their land back, while in a large part of the Former Soviet Union households had never owned land, since feudalism had directly preceded collectivist farming.

Another condition that played an important role was that in Central Europe and the Baltic states, countries were generally richer and agriculture was less

Table 10.13. Pre-reform indicators

	Share of Agricultural Employment in Total Employment (%)	GNP Per Capita (PPP $ 1989)	Labor/Land (persons per ha[a])	Years of Central Planning (number)
Central Europe				
Czech Republic	9.9	8,600	0.122	42
Hungary	17.9	6,810	0.131	42
Poland	26.4	5,150	0.258	41
Slovakia	12.2	7,600	0.139	42
Balkan				
Albania	49.4	1,400	0.627	47
Bulgaria	18.1	5,000	0.132	43
Romania	28.2	3,470	0.204	42
Slovenia	11.8	9,200	0.116	46
Baltics				
Estonia	12.0	8,900	0.072	51
Latvia	15.5	8,590	0.085	51
Lithuania	18.6	6,430	0.098	51
European CIS				
Belarus	19.1	7,010	0.105	72
Moldova	32.5	4,670	0.269	51
Russia	12.9	7,720	0.044	74
Ukraine	19.5	5,680	0.118	74
Transaucasia				
Armenia	17.4	5,530	0.218	71
Azerbaijan	30.7	4,620	0.203	70
Georgia	25.2	5,590	0.217	70
Central Asia				
Kazakhstan	22.6	5,130	0.008	71
Kyrgyzstan	32.6	3,180	0.054	71
Tajikistan	43.0	3,010	0.185	71
Turkmenistan	41.8	4,230	0.015	71
Uzbekistan	39.2	2,740	0.109	71

Source: Macours and Swinnen 2002.
Note: Pre-reform indicators are for 1989 for the Central and Eastern European countries and for 1990 for the Former Soviet Union republics.
[a]Number of full-time agricultural workers in agriculture.

important in the overall economy, compared to countries in Transcaucasia and Central Asia, which were much poorer with relatively more important agricultural sectors. The general economic situation in a country influenced the extent to which other sectors could absorb surplus labor from agriculture and the development of the social safety net system. Finally, the outflow of surplus agricultural labor was much stronger in Central Europe than in other countries in the 1990s, in part because the social safety net system was much better developed in Central Europe and the agricultural sector was relatively small.

Finally, the resource endowments and technology use affected farm restructuring and the relative efficiency of farm organizations (see Section 5.4).

5.2. Price Liberalization and Subsidy Cuts

In all regions, prices of outputs and inputs were determined by the central planning authority. Generally, trade and price liberalizations caused a dramatic fall in the agricultural terms of trade in all regions, because output prices were well above equilibrium prices and input prices were heavily subsidized. This contributed to a fall in input use at the start of the reforms, which caused a decrease in productivity of labor and land (Macours and Swinnen 2000).

However, the implementation of these reforms and thus the effect on productivity differed substantially among regions. Governments in Central Europe and the Baltic states dramatically reduced agricultural subsidies in the early transition period, whereas in some European CIS and countries in Central Asia reforms were more gradual (Hartell and Swinnen 1998; Csaki and Nash 1997; Csaki and Fock 2001). For example, in the early transition period, Russia liberalized its output prices but retained some input support. In other countries, such as Turkmenistan, Uzbekistan, and Belarus, agricultural support remained intact until the end of the 1990s. In Central Europe, economic recovery triggered the demand for the reintroduction of more agricultural support. In most countries agricultural support started to increase at the end of 1990s (Figure 10.8), and more recently these countries have benefited from EU subsidies.[2]

[2]In all of the Central and Eastern European countries (expect Slovenia), the accession to the European Union led to the implementation of a simplified income support scheme, the Single Area Payments Scheme (SAPS). In principle, SAPS consists of a fixed per hectare payment, uniform over all types of land. Although the payments are uniform within one country, they differ substantially among countries. These variations stem from the fact that the rate of per hectare payments is determined based on historical yields (2000-2002) in the different countries. These different yields resulted in substantial differences in the payments per hectare among the Central and Eastern European countries.

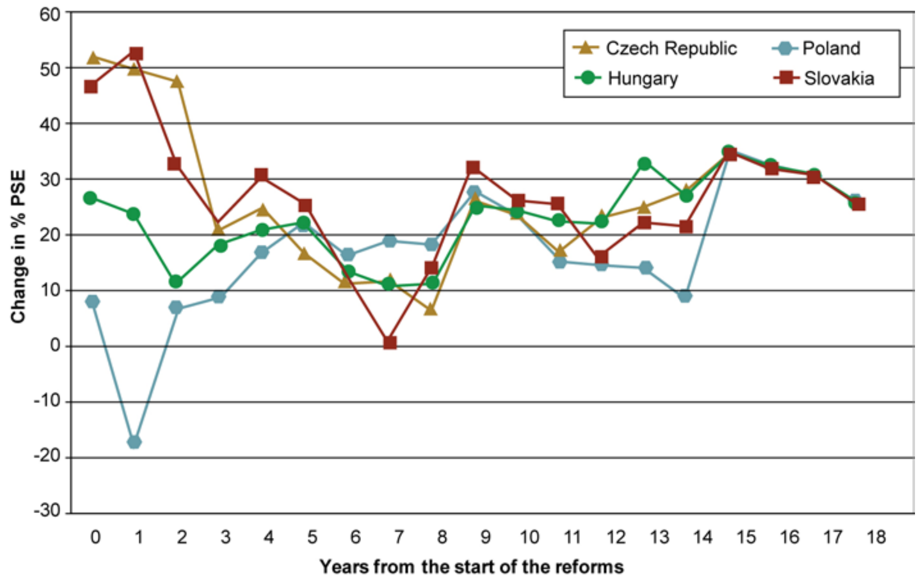

Figure 10.8. Evolution of producer support estimate (PSE) in Central Europe
Source: OECD 2008.
Notes: Czech Republic, Hungary, Poland, and Slovakia from 2004: %PSE of the EU25-27. Reforms started in 1989 (=year 0) in Central Europe and the Balkan countries and in 1990 (=year 0) in the Baltic states, the European CIS, Transcaucasia, and Central Asia.

5.3. Privatization and Land Reform

A very important element of the reform packages was land reform. Different approaches to land reforms affected the restructuring and structural change in the agricultural sector. In general, three approaches to land reforms were applied: restitution, physical distribution, and distribution of paper shares or certificates (Macours and Swinnen 2002).

First, except for Poland and Albania, land was restituted to the former owners in the Central European countries, the Baltic states, and the Balkan countries. In these countries, where collectivization was imposed only after World War II, land was restituted to the former owners (or their heirs) within the historical boundaries. If restitution was not possible, former land owners (or their heirs) received a plot of comparable size and quality. Second, in Albania, Romania (partly), Armenia, and Georgia, land was physically distributed on an equal basis to agricultural workers or rural households. Third, in the European CIS and Central Asia, paper shares or certificates were distributed equally to collective farm members or state employees. This land reform process consisted of two steps: first, land ownership rights were transferred from the state to the collective farm, and second, land ownership rights were transferred from the collective farm to the individuals. The land rights were transferred as paper shares or certificates, without any direct link between the individual and a specific plot of land.

In general, the process of privatization and land reform was complicated and slow, which slowed down effective liberalization and prolonged the uncertainty of property rights. As long as property rights were uncertain, markets could not develop, and the decapitalization of the agricultural sector continued through livestock slaughtering and reduced investments (Macours and Swinnen 2000a).

The first and second types of land reform, restitution and the physical distribution, ended up with relatively strong and well-defined property rights. Yet, it was expected that restitution of land would lead to a decrease in productivity, because it entailed fragmentation of agricultural land ownership. However, in many countries restitution contributed to a greater consolidation of land use. Mathijs and Swinnen (1998) explained this using a measure of transaction costs associated with land markets. Restitution of land transferred land rights to the former owners, many of whom were often no longer active in agriculture. These new landowners, except those in poor countries, were not interested in engaging in farming activities. Because the costs of negotiation and search associated with finding new potential renters were too high, the new owners rented out the land to the farm that had been using the land, which was typically the large-scale farmer-cooperative farm. So despite the great fragmentation of property rights, restitution did not lead to more fragmented land use.

In the regions that implemented land reforms by distributing certificates, property rights were less clearly defined, and, at least in the first decade of the reforms, output and productivity were affected as a result. First, restrictions were placed on selling and purchasing shares, and in many countries it was not possible to buy or sell land, which significantly slowed down structural changes and thus productivity growth (Lerman 2001). Second, owners had little incentive to put in effort and undertake investments because property rights on specific plots were not clearly defined (Uzun 2000). Uncertainty on the property rights resulted in a decrease of agricultural output and productivity. However, at the end of the 1990s the situation started to improve when land policies were further liberalized, and limited land transactions became possible, for example, in 2002 in Russia (Rozelle and Swinnen 2004).

5.4. Farm Restructuring

Important productivity gains and losses were associated with farm restructuring. The effects of these gains and losses depended on the initial conditions, such as farm structure and technology used, and the reform policies that were implemented, such as the land reform policies and the general macroeconomic reforms.

The initial conditions, in particular resource endowments and use of technology, affected the relative efficiency of farm organizations and thus incentives for farm restructuring. Resource endowments affect the costs and benefits of shifting from corporate farms to family farms. If labor/land ratios are high, as in countries with labor-intensive technologies, such as in Transcaucasia and the Balkans, the benefits from better labor governance by shifting to family farms from corporate farms are larger, while the losses in scale economies of shifting to smaller farms are lower. These productivity incentives resulted in a strong shift to small-scale farming. In contrast, in more capital- and land-intensive agricultural systems, such as in the Czech Republic and Slovakia, the benefits from shifting to family farms were lower so that large-scale corporate farming remained more important. In these situations, productivity gains came mostly from laying off corporate farm workers. The impact of privatization and farm restructuring also depended on accompanying policy reforms, both in the agricultural sector and in the general economy. First, it depended on the way land reforms were implemented (see section 5.3).[3] Second, it depended on other economic reforms. Labor can flow out from the agricultural sector only if there are sufficient employment alternatives and social security payments. If the unemployment rate is high and unemployment benefits are low, agriculture serves as a social buffer and attracts young, often unmotivated individuals. Low pensions have a similar effect because old people start farming to complement their pensions.

5.5. Foreign Direct Investments in the Agri-Food Industry

An important factor in the decline of both output and productivity was the disruption of vertically coordinated supply chains (Blanchard 1997; Gow and

[3]In Transcaucasia the shift toward more individual land use was limited in the early years of transition because the privatization process was slow, but later there was an increasing number of small, individual farms. In many countries in the region the share of output from individual farms is much larger than their share in land use, suggesting that the individual farmers are more efficient producers and typically produce more labor-intensive products with a higher value added (Table 10.14).

Table 10.14. Privatization and land reform

	Individual Land Use (%)			Individual Production (%)	
	Pre-reform	After 5 years	After 8/9/10 years	Pre-reform	After 7 years
Central Europe					
Czech Republic	1	19	26	n.a.	n.a.
Hungary	13	22	54	n.a.	n.a.
Poland	76	80	84	n.a.	n.a.
Slovakia	2	5	9	n.a.	n.a.
Balkan					
Albania	3	95	n.a.	n.a.	n.a.
Bulgaria	14	44	56	n.a.	n.a.
Romania	14	71	82	n.a.	n.a.
Slovenia	83	90	94	n.a.	n.a.
Baltics					
Estonia	4	41	63	n.a.	n.a.
Latvia	4	81	87	n.a.	n.a.
Lithuania	9	64	85	n.a.	n.a.
European CIS					
Belarus	7	16	12	25	45
Russia	2	8	13	24	55
Ukraine	6	10	17	27	53
Transaucasia					
Armenia	7	95	90	35	98
Azerbaijan	2	5	n.a.	35	63
Georgia	12	50	44	48	76
Central Asia					
Kazakhstan	0	5	24	28	38
Kyrgyzstan	4	34	37	34	59
Tajikistan	04	5	9	23	39
Turkmenistan	2	3	8	16	30
Uzbekistan	5	13	14	28	52

Sources: Csaki and Tuck 2000 and Macours and Swinnen 2002.

Swinnen 1998). Investments by private processors and the reintroduction of vertically coordinated supply chains have been important in improving output, productivity, and quality of agricultural products. Foreign direct investment (FDI) in the agri-food sector has played a leading role in these developments through both horizontal and vertical spillover effects on, respectively, domestic processors and farmers.

Prior to the reforms, the entire agri-food chain, from input supplier to consumer, was planned and controlled by a higher central authority. The reform to a market-oriented economy led to the disruption of the agri-food chain, and because of macroeconomic instability and institutional reforms, contract enforcement was no longer guaranteed and all parties in the supply chain were confronted with hold-up problems (Gow and Swinnen 1998; Stiglitz 1993; Hart 1995).

Farmers were not willing to supply to a processor because they feared payment delays or even no payments at all (Gorton, Buckwell, and Davidova 2000; Cungu et al. 2009). If they wanted to supply they often lacked the basic input factors or expertise to produce a certain quantity or quality. Vertical coordination of the supply chain was the solution for processors to guarantee to supply a certain quantity and, later on, also a certain quality.

FDI companies were the first to reintroduce vertically coordinated supply chains through the introduction of an input supply program and farm extension services. In the early stage of transition, processors first wanted to ensure their supplies by introducing input supply and credit programs. In the more advanced stage, they also tried to ensure product quality and offered farmers extension services and training programs. Examples of the first stage can be found in Romania, Bulgaria, and some countries in Central Asia, whereas the second stage is widely seen in the Central European countries. The existence of these different stages indicates that the development of economically more advanced input supply programs is positively correlated with the extent of institutional reform in the countries, because the introduction of these programs requires well-functioning institutions.

Case studies have indicated that there are important horizontal spillovers from these contract innovations on domestic companies that quickly start imitating successful contracting and vertical integration programs introduced by foreign firms (Dries and Swinnen 2004; Gow, Streeter, and Swinnen 2000). Besides horizontal spillovers to other processors, the introduction of the input supply programs also had vertical spillovers to the agricultural producers. The use of input supply programs by agricultural producers who are often credit-constrained led to significant improvements in output, productivity, and quality. A case study of sugar production in Slovakia found that the introduction of farm assistance schemes in the mid-1990s led to an annual increase of sugar beet yields of 9% in the period 1993-1997 (Gow, Streeter, and Swinnen 2000). In a case study on Moldova, Armenia, Georgia, Russia, and Ukraine, White and Gorton (2004) found that contracting resulted in an annual increase of 3% in productivity and a 4% increase in high-quality output on average over the period 1997-2003.

Empirical evidence on FDI per capita in the different Former Soviet Union republics (Figure 10.9) indicates that in the mid–transition period, FDI strongly increased in Central Europe and the Baltic states. In the Balkan states, the inflow of FDI lagged behind that of Central Europe and the Baltic states. However, after the financial crisis at the end of the 1990s, FDI started to increase. In the most recent years, FDI increased even more strongly in Central Europe and the Balkan countries, suggesting that accession to the European Union has led to a more stable institutional environment, which is necessary to attract FDI. In the European CIS, Transcaucasia, and Central Asia, FDI inflow has been very low, although in the most recent years it increased slightly.

6. CONCLUSION

There have been dramatic changes in agricultural productivity over the past two decades in Central and Eastern Europe and the Former Soviet Union. In general, we observe a "J" (or "U") effect: an initial decline in productivity and a recovery later on. However, the depth of the decline, the time until recovery, and

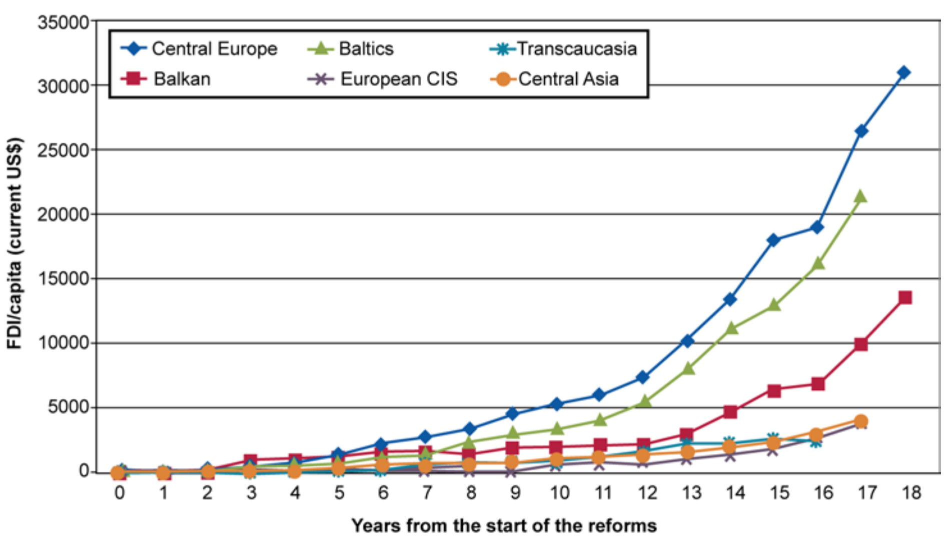

Figure 10.9. Evolution of FDI per capita in selected Former Soviet Union republics

Source: UNCTAD 2008.

the growth in productivity afterward differed strongly among countries and were influenced by the initial conditions, reform policies, and investments in the agri-food industry. We can distinguish four groups with similar patterns.

In the first group are the most economically advanced countries in Central Europe and the Baltic states, such as Hungary, the Czech Republic, Slovakia, and Estonia, which implemented radical reforms. These countries are 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 the 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 in the early transition period. Later, productivity gains were reinforced by spillovers from the large inflow of FDI in the agri-food sector. Investments, through vertically integrated supply chains, improved farmers' access to credit, technology, inputs, and output markets.

A second pattern can be seen in the poorer countries in Central Europe and the Balkan states, including Romania, Bulgaria, Lithuania, and Poland. These countries were very 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 countries, labor outflow from agriculture was limited in the early transition period. 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 the 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 breakup 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–transition period 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 2000, 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 substantially below pre-reform levels in Transcaucasia.

A fourth pattern is seen in a group of middle-income Former Soviet Union 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 budget constraints 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 particularly affected 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 since 2000 was increased investments in the food industry, which benefited agriculture through vertical integration.

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CHAPTER 11

The Changing Pattern and Sources of Agricultural Growth in India

Alka Singh and Suresh Pal

1. INTRODUCTION

The Indian economy has moved decisively to a higher path of growth in recent years, making it one of the fastest-growing economies in the world. The rate of economic growth measured in real per capita gross domestic product (GDP) (1999-2000 prices) averaged less than 5% per year during the 1980s and 1990s, increasing to more than 7% per year during the period 2003-07 (Planning Commission 2008). The economy is now poised to sustain these more rapid rates of expansion, with the potential to bring significant improvements to the lives of millions of the country's poor.

In contrast, the country's agricultural economy has performed erratically during the past several decades. Indian agricultural output, especially that of rice and wheat in irrigated areas, recorded a quantum jump in growth during the 1970s and 1980s in response to the widespread adoption of new seed- and fertilizer-based technologies. This was accompanied by substantial growth in rural infrastructure, mainly through public investments. The growth stimulus spread into rain-fed agricultural production beginning in the 1980s with the rapid adoption of high-yielding varieties of coarse cereals, oilseeds, pulses, and cotton. Rising yield growth and cropping intensities greatly contributed to buoyant agricultural growth, despite frequent instability due to weather events. The livestock sector, the second-largest component of India's agricultural GDP, also

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has had exemplary growth since the 1980s. However, this impressive overall growth performance obscures very different growth rates across different sectors, states, and social groups.

In recent years, agricultural growth has slowed, with wide year-to-year fluctuations. Beginning in the early 1990s, agricultural growth was substantially below that of the non-agricultural sector, and the gap is widening. The comparatively slow growth of agriculture would perhaps have been of less concern if there had been a commensurate decline in the percentage of the population dependent on agriculture. But this has not been the case; in fact, the official statistics showed that the agricultural population has continued to increase. This widening gap may seriously jeopardize the national goal of inclusive economic growth, as two-thirds of India's population still depends on agriculture and allied sectors for gainful employment and a secure livelihood.

The difficulty of improving agricultural productivity on a sustainable basis is further compounded by increasing pressure on natural resources and the environment, the vulnerability of agriculture to external shocks like climate change, and the fragmentation and small scale of Indian farms. Given these natural resource and structural constraints, agricultural growth must increasingly rely on sustained and improving productivity growth through continued technological and institutional innovations. There are some positive developments on these fronts that have helped maintain agricultural growth at a reasonable level and have thereby insulated the country from the recent global food crisis. In this chapter we examine the broad pattern of agricultural growth in the country, its sources and regional dimensions. We particularly underscore the recent success stories, diversification patterns, and binding constraints.

In the next section we present the main characteristics of Indian agriculture and its changing contribution to India's national economy. This is followed by a detailed discussion of the pattern of growth in agriculture, and the regional and commodity dimensions of that growth. Trends in total factor productivity are also reviewed at length in Section 3. An in-depth analysis of sources of growth in Indian agriculture—particularly recent trends in public investment such as irrigation, research, and infrastructure development—is provided in Section 4. In Section 5, we address challenges faced by Indian agriculture and the possible strategies for dealing with them. We conclude the chapter with some observations about options for accelerating India's agricultural growth.

2. AGRICULTURE IN THE INDIAN ECONOMY

The Indian economy has grown at an impressive rate in recent times. This sharp uptrend in growth can be attributed in (perhaps significant) part to a series of economic reforms initiated by the government in the early 1990s. The composition of growth has also changed substantially. In earlier times, agricultural and manufacturing sectors fueled much of the country's economic growth. Since the 1990s, a newly emerging services sector has been the main driver of growth, along with manufacturing, while the relative contribution of agriculture to current economic growth has shrunk significantly. Agriculture's share of Indian GDP fell from 37.9% during the early 1980s to less than half of that share (17%) during 2008-09. However, in real terms, Indian agriculture has continued to grow, albeit at varying rates, owing to several factors. Agriculture has an impressive long-run record, from delivering the country from serious food shortages, to becoming food self-reliant, to growing a food-surplus economy. Agriculture still contributes significantly to export earnings and is an important source of raw materials and demand for the booming non-agricultural sector. The country is increasingly taking its place in the global production marketplace as a leading producer of many agricultural commodities, including milk, wheat, rice, and cotton.

The shifting contribution of agriculture and other sectors of the economy is quite consistent with the evolution of economic growth witnessed in the developed countries. In contrast to the slowdown in the rate of growth of agricultural output, non-agricultural GDP shows a robust and rising growth trend. And while agriculture's share of total employment has declined, it is still a dominant source of employment, from employing 73.9% of the economically active population in 1973-74 down to 56.5% in 2004-05. A comparison of agriculture's share of domestic output and employment shows that the decline in agriculture's share of the labor force is slower than the decline in its share of output (Table 11.1). This clearly indicates the increasing gap between average incomes of workers engaged in agricultural and non-agricultural occupations and also highlights the inability of the non-agricultural sector to provide gainful employment to the masses.

Agricultural GDP grew by 3.5% per year during the 1980s (characterized by wider technology dissemination), which was substantially slower than the rate of growth of either the non-agricultural sector or the overall economy (Table 11.1). The 1980s pace of growth carried through to the middle of the 1990s, but thereafter agricultural growth slowed to 2.5% for the following decade against a target

Table 11.1. Share of agriculture in India's gross domestic product and employment

Period	Agriculture and Allied Sector's Share[a]		Real Average Annual Growth Rate		
	Total GDP at Factor Cost	Share in Employment[b]	Total GDP	GDP Agriculture and Allied Sector	GDP Non-agriculture
	(percentage)		(percent per year)		
1981-82 to 1990-91	31.4	61.0	5.4	3.5	6.4
1991-92 to 1996-97	27.8	56.6	5.7	3.7	6.6
1997-98 to 2006-07	18.5	52.1	6.6	2.5	7.9

Source: MoF (*Economic Survey, 2007-08*).
Note: Nominal values deflated to 1999-2000 prices.
[a]The share was computed only for the terminal years.
[b]Data pertain to 1993-94, 1999-00, and 2004-05, respectively.

growth of 4% per year[1] (Planning Commission 2008). The main challenge to India's agricultural sector continues to be the failure to meet growth targets, along with degraded natural resources, the predominance of rain-fed agriculture, and a preponderance of small farmers.

2.1. Structural Changes in Agriculture

Though the relative contribution of agriculture to the national economy has changed, the basic characteristics of Indian agriculture have not. Indian agriculture continues to be dominated by smallholders; in fact, their number has risen much faster in the recent period. As a result, there has been a significant reduction in the average size of a farm holding—close to one hectare at present (Table 11.2). Net cultivated area remains at around 140 million hectares, and more than half of this area is rain-fed. Much of the agricultural production is for domestic consumption, and only about one-tenth of the total value of production is exported. The output of food grains has registered a two-fold increase since the early green revolution period (1970), and output has jumped again in recent years. One significant shift in the growth process has been its source, with much of the more recent (post-1980) increase in output attributable to yield growth, followed by changes in cropping patterns, with a minimal contribution of area growth.

[1]The Government of India envisaged annual growth of 4% per year in the agriculture sector in its National Agricultural Policy, 2000, and Eleventh Five Year Plan (2007-2012).

Table 11.2. Major trends in Indian agriculture

Indicator	1971	1981	1991	2001	2006
Average size of holding (ha)	2.30	1.84	1.57	1.33	n.a.
Net cultivated area (mha)	139.72	141.93	141.63	141.45	141.89
Total cropped area (mha)	165.19	176.75	182.24	189.75	192.80
Total irrigated area (mha)	38.43	51.41	65.68	78.73	82.63
Share of rural population (%)	80.1	76.7	74.3	72.2	n.a.
Share of exports in AgGDP (%)	2.7	3.9	4.4	6.1	9.1
Share of agriculture in national GDP (%)	40.6	34.4	29.6	23.2	18.2
Total food grain production (million tons)	105.17	133.30	168.38	212.85	217.28
Food grain yield (metric tons/ha)	0.85	1.03	1.38	1.73	1.76

Sources: Compiled from MoA (various years) and CSO (various years).

The crop sector continued to be a principal component of overall agricultural output, accounting for more than two-thirds of the value of agricultural output in 2008, with the livestock sector accounting for about one-quarter of total output (Table 11.3). Since the early 1980s there has been a modest decline in the crop sector's share of agricultural output while the livestock and fisheries sectors increased their respective market shares. The increasing share of output coming from the livestock sector—17.5% in the triennium ending (TE) 1981 to 24.5% in 2006 (Table 11.3)—reflects both supply-side and demand-side factors. Livestock production is considered to be remunerative and labor intensive, and thus it suits the needs of smallholders. At the same time, Indian farmers are responding well to opportunities in commercial agriculture and diversifying to meet the rising demand for livestock products. Milk and milk products now make a major contribution to livestock output, such that India is now the largest milk producer in the world. The livestock sector has also diversified, with more production of poultry meat and eggs over recent years. The fishery sector still accounts for less than 5% of agricultural GDP, albeit with a steadily increasing share over the past several decades. However, the sector saw a considerable shift from marine to inland production, with inland production becoming increasingly important of late.

The crop sector is dominated by food grains production, which accounted for about 64.5% of the total cropped area during 2005-06. Food grains production increased markedly, to total 230 million metric tons in 2008, through

Table 11.3. Production shares and amounts by category, and selected crop yields

Indicator	TE 1981	TE 1991	2008
Share in the total value of production (%)			
Crop	75.5	70.6	67.1
Livestock	17.5	22.0	24.5
Forestry	5.2	4.7	3.6
Fishery	1.7	2.7	4.8
Agricultural production			
Food grains production (mt)	124.20	172.45	230.67
Milk production (mt)	31.60	51.23	100.87
Fish production (mt)	2.44	3.55	6.87
Egg production (billion, number)	10.06	20.10	50.66
Crop yields (t/ha)			
Rice	1.25	1.72	2.20
Wheat	1.71	2.33	2.79
Coarse cereals	0.69	0.88	1.42
Pulses	0.46	0.58	0.64
Cotton	0.16	0.23	0.47
Groundnut	0.84	0.88	1.46

Sources: Share of value of production from CSO (various years) and remaining data from MoA (various years).
Note: TE indicates triennial ending.

tripling the average yield of principal crops since the early 1950s. The share of cereals production decreased from 39% in TE 1981 to 30% in TE 2006, while that of fruits and vegetables increased from 16% to 25% during the same period. Oilseeds peaked in terms of their market share in TE 1991 and then lost ground thereafter. These trends show that the crop sector is diversifying toward non-food grains and high-value commodities such as fruits and vegetables. The share of overall output coming from pulses and fibers changed little over the years, while sugar marginally increased its share of total crop output (Table 11.4). The changing composition of agricultural output is well reflected in the growth of value of agricultural output, which has shown a significant increase since the early 1990s (Figure 11.1). On the input front, the share of purchased inputs in value of output from agriculture including livestock hovered around 22% during the same period. Gains in rice yields were higher than those of wheat during the period. More significant is the marked increase in the yields of cotton and coarse cereals, indicating rapid diffusion of new technologies even in rain-fed areas. (Table 11.3).

Table 11.4. Compositional changes within crop sectors

Crop Group	TE 1981	TE 1991	TE 2001	TE 2006
		(percentage)		
Cereals	38.7	35.9	33.8	30.1
Pulses	6.1	6.4	4.9	5.2
Oilseeds	8.6	12.0	7.9	8.5
Fruits and vegetables	16.3	17.2	24.1	25.0
Sugar	5.1	4.9	6.4	7.3
Fibers	4.4	4.3	3.3	4.0

Sources : CSO (various years), NAAS (2009).
Notes: TE indicates triennial ending. Data are percent shares of value of crop productions.

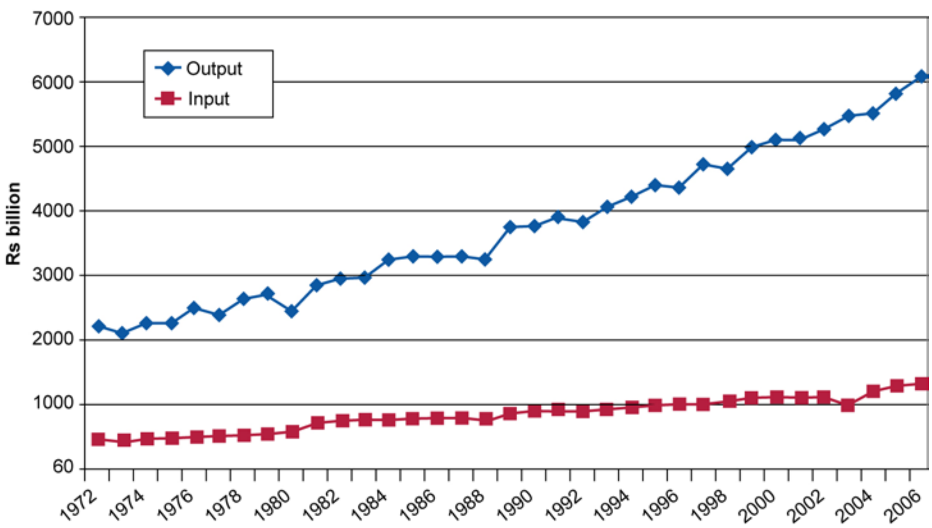

Figure 11.1. Value of agricultural output and input (1999-2000 prices)
Source: Period from CSO (various years, www.mospi.gov.in).
Note: Nominal values deflated to 1999-2000 prices.

2.2. Agricultural Trade

India's agricultural trade is diverse, ranging from raw products to processed and ready-to-eat items. The share of India's agricultural exports in total exports has varied between 11% and 15% since 2000. During 2007-08, the value of agricultural exports totaled more than U.S.$7 billion, of which marine products and oil meal were among the largest contributors. The composition of agricultural trade has changed significantly in the recent period. The proportion of Indian agricultural exports coming from fruits and vegetables, flowers, cotton, sugar and molasses, and livestock products has increased considerably. Cereals (mostly basmati and non-basmati rice), tea, coffee, cashews, and spices are other prominent products, each accounting for between 5% and 10% of the country's total agriculture exports. India's agricultural imports, on the other hand, have constituted only a small portion of the country's total imports (less than 5%) during the current decade. The country imports mainly vegetable oil and pulses, which alone account for about 70% of total agricultural imports.

3. AGRICULTURAL GROWTH PATTERN

Agricultural growth was significant during the 1980s and early 1990s, as evidenced by the performance of the crops, livestock, and fisheries sectors (Table 11.5). The crop sector showed modest (but still substantial) growth during the early 1990s, but it consistently slowed down thereafter. The rate of growth in livestock production also began to slow in the mid-1990s but has remained higher than the corresponding rate of growth in food grains and oilseeds. There is a noticeable decline in growth rates after the mid-1990s across all agricultural sectors, with growth in some sectors (including pulses and oilseeds, livestock, and fisheries) rebounding in recent years. A substantial cause for concern has been the ratcheting down in the pace of growth of cereals output in recent decades, given the fact that the substantial share of agricultural output still derives from this sector and is the mainstay of India's food security. Consequently, the

Table 11.5. Period average growth of real agricultural output by sector

	Crops						
Period	Cereals	Pulses and Oilseeds	Fruits and Vegetables	Other Crops	All Crops	Livestock	Fishery
	(percent per year)						
1981-82 to 1990-91	3.52	5.41	2.84	1.71	2.97	4.78	5.74
1991-92 to 1996-97	2.36	2.92	6.07	2.18	3.09	4.00	7.05
1997-98 to 2001-02	1.49	-1.43	4.11	3.82	2.25	3.53	2.63
2002-03 to 2006-07	1.28	4.29	2.97	2.25	2.46	3.69	3.23

Source: Planning Commission (2008).
Note: Respective nominal totals deflated to 1999-2000 prices.

overall rate of growth of agricultural GDP has been well below a target rate of 4% per year. The annual data suggest that the rate of growth of crop output peaked by the mid-1990s and has slowed afterward. In contrast, the horticulture sector exhibited impressive output growth throughout the entire 1990s. Although it, too, slowed thereafter, it has sustained a rate of output growth that is more than twice as fast as the corresponding growth in cereals output. However, food grain production spiked in 2008 as global commodity prices soared, while the high-value livestock, fisheries, and fruits and vegetables sectors sustained growth rates of at least 3% per year.

One fact concealed in these period averages is the wide year-to-year fluctuations in growth performance. In some years, growth rates increased by as much as 10% (between 2002-03 and 2003-04) compared with the average growth of 4.5% between 2002-03 and 2006-07. Unfavorable weather conditions corresponded with low-growth years, and these lowered the overall growth rate. However, excluding the abnormally poor years of 2002-03 and 2004-05, the average growth of GDP from agriculture and allied sectors (1999-2000 prices) during the 1997-98 to 2008-09 period was estimated at 3.7% per year.

3.1. Agricultural Diversification

Indian agricultural production began to diversify gradually in the 1980s, as reflected by changes in sectoral and crop contributions to the total value of agricultural output, and this trend began to accelerate during the 1990s. This pattern is visible in the distinctly different growth patterns between food grains and non-food grains. The share of area under food grains has declined since the early 1980s, with a small decline in the share of area under rice and wheat, compounded by a marked decline in the area under coarse cereals (Table 11.6). Notwithstanding these shifting area shares, the yields of coarse cereals grew at markedly higher rates than yields for other grains such as rice and wheat, especially during the 1990s (Table 11.6). The official statistics show that about 60% of the cropped area for coarse cereals in the late 1990s was planted to high-yielding varieties, even though the coverage of irrigation was much lower for coarse grains. Among the food grains, the growth scenario is completely different for pulses, as shown by the crop's declining growth in output, area, and yield, especially during the 1990s. However, during the last decade, there was appreciable acceleration in the growth of pulse production, owing to growth in both area and yield. The growth performance of oilseeds as a group surpassed that all of

Table 11.6. Area, production, and yield growth rates of principal crops in India

	1980-81 to 1990-91			1990-91 to 1999-2000			2000-01 to 2006-07		
Crop Group	Area	Production	Yield	Area	Production	Yield	Area	Production	Yield
					(percent per year)				
Food grains	-0.23	2.85	2.74	-0.07	2.02	1.52	0.48	2.09	2.82
Cereals	-0.26	3.03	2.90	0.04	-0.02	1.59	0.16	1.95	3.10
Coarse cereals	-1.34	0.40	1.62	-2.12	-0.02	1.82	-0.41	3.25	4.25
Pulses	-0.09	1.52	1.61	-0.60	0.59	0.93	1.91	3.42	1.65
Non-food grains	1.12	3.77	2.31	1.18	2.69	1.09	2.46	5.09	3.87
Oilseeds	1.51	5.20	2.43	-0.86	1.63	1.15	2.71	6.69	4.91
Cotton	-1.25	2.80	4.10	2.71	2.29	-0.41	1.45	17.48	15.79
All principal crops	0.10	3.19	2.56	0.27	2.29	1.33	1.06	3.17	3.80

Source: MoA (2008).

Notes: Area represents planted area of each crop category. Area, production, and yield growth rates calculated as annual average growth of respective area, output, and yield indexes (base: triennium ending 1981-82=100).

other crop groups during the 2001-07 period and was distinctly superior to its past rates of growth. Both area and, particularly, yield components contributed significantly to this dramatic expansion in output. More importantly, unlike the slowdown in output growth of cereals and pulses during the 1990s, oilseed output continued to expand. Of India's major cash crops, cotton merits special mention because of its strong growth performance, especially in recent years. This was made possible mainly through significant advances in seed technology, especially Bt cotton and the resulting high growth in yield per hectare (Qaim et al. 2006; Gandhi et al. 2006).

The livestock sector is also noteworthy, as its overall growth performance outpaced that of the crop sector by a wide margin, enabling the country to enjoy higher per capita availability of milk and other livestock products. However, the pace of growth dropped steadily, from 4.8% in the 1980s to 3.7% during 2002-06 (Table 11.5). Milk and milk products constitute around two-thirds of all livestock output (by value) and thus heavily influence the overall trend for the sector. However, considerable diversification toward production of poultry meat and eggs has occurred, as evident from the spectacular growth of these commodities since the 1980s. The share of meat and meat products in total agricultural output has remained fairly stable over the last three decades (Chand and Raju 2008).

What are the major drivers of agricultural diversification toward high-value commodities? There are a number of factors responsible for this shift. The most important among these is greater demand for high-value commodities such as fruits, vegetables, and livestock products as per capita incomes increase. As incomes rise, people consume more higher-value commodities and less traditional food items such as cereals. This effect has been more pronounced in the recent past because of the spectacular growth in the Indian economy. Demographic changes are also at play, including increased urbanization, increased female literacy, and increased participation of women in the workforce, especially in urban areas and small towns. These demand-side factors were matched by positive developments on the supply side. Farmers responded to the incentives offered by high-value commodities, both for domestic and international markets. This was particularly true for the fruits and vegetables, poultry, and fisheries sectors, in which new farming opportunities and technologies emerged. Imports of improved seed varieties and planting materials were permitted under a new seed policy introduced during the late 1980s. Because these commodities provided comparatively high and regular returns to smallholders in a short period, farmers directed resources to these areas. Finally, the participation of the private sector in retail marketing and input supply and other production-enhancing undertakings, including new forms of contractual arrangements with growers, provided further impetus to the growth of high-value commodities (Joshi, Gulati, and Cummings 2007).

3.2. Regional Patterns of Agricultural Growth

The structure and regional distribution of agricultural production varies markedly among regions and states. At the national level, the rate of growth in net state domestic product (NSDP)[2] from agriculture slowed significantly when comparing the period 1984-85 to 1995-96 with the period 1995-96 to 2004-05 (Table 11.7). Almost all the major states of India, except Bihar and Orissa, the two poorest states, exhibited impressive rates of growth during the earlier period. This period is in fact a turning point in Indian agriculture, as the sector witnessed not only impressive growth rates but also better distribution of growth among different states of the country. Notable was the growth performance of the rain-fed states of Madhya Pradesh and Rajasthan, primarily because of large shifts from coarse cereals to oilseed production. The shift toward oilseeds reflected the commodity's relative profitability fueled by an appreciable increase in administered prices coupled with a faster rate of yield growth compared with coarse cereals. Both these effects were realized through concerted government efforts under the Oilseed Mission.[3] Another important development was the impressive growth performance of West Bengal, especially in rice production. The spread of modern seed varieties and an increase in area cultivated under summer (*boro*) paddy with improved irrigation and input management contributed to this performance. Gujarat also deserves special mention, as it has attained 9.6% growth per year in agricultural state domestic product since 1999-2000. The main sources of its growth are a massive boom in cotton production, growth in high-value commodity groups like livestock, and fruits and vegetables, and wheat production (Gulati, Shah, and Shreedhar 2009).

The national slowdown in agricultural output growth during the post-1995-96 period was evident in all states except Bihar. The slowdown even affected

[2]NSDP is one of the important indicators for measuring economic growth in states and union territories of the country.

[3]The Oilseed Mission was launched by the Indian government in 1986 to increase oilseed production and achieve self-sufficiency in edible oils. Subsequently, pulses, oil palm, and corn were also brought within the purview of the Mission in the early 1990s.

Table 11.7. Measures of state agricultural and economy-wide activity

State	Growth of Net State Domestic Product in Agriculture 1984-85 to 1995-96	Growth of Net State Domestic Product in Agriculture 1995-96 to 2004-05	Net State Domestic Product 2007-08	Yield of Food Grains 2006-07	Rural Population Below the National Poverty Line 2004-05
	(percent per year)		(Rs/ha, 1000s)	(t/ha)	(percent)
Punjab	4.00	2.16	53.4	4.02	9.10
Haryana	4.60	1.98	48.5	3.39	13.60
Uttar Pradesh	2.82	1.87	37.4	2.06	33.40
Tamil Nadu	4.95	-1.36	64.2	2.61	22.80
West Bengal	4.63	2.67	69.0	2.51	28.60
Bihar	-1.71	3.51	35.2	1.66	42.10
Andhra Pradesh	3.18	2.69	56.4	2.23	11.20
Gujarat	5.09	0.48	34.1	1.42	19.10
Rajasthan	5.52	0.30	19.1	1.12	18.70
Orissa	-1.18	0.11	27.7	1.36	46.80
Madhya Pradesh	3.63	-0.23	17.7	1.17	36.90
Maharashtra	6.66	0.10	34.1	0.94	29.60
Karnataka	3.92	0.03	28.4	1.29	20.80
Kerala	3.60	-3.54	74.6	n.a.	13.20
Assam	1.65	0.95	47.3	1.29	22.30
All India	3.62	1.85	40.6	1.76	28.30

Sources: State domestic product from CSO (various years); yield from MoA (2008); poverty indicator from Planning Commission.

the comparatively well developed northwestern region of the country, including states such as Punjab and Haryana. Many other states in rain-fed regions of the country, which account for 60% of the total cultivated area, also saw significantly poorer growth performances during this period. These rain-fed areas are characterized by relatively higher incidences of poverty, more limited (off-farm) employment opportunities, higher production risks, and high rates of out-migration, and thus the slowdown in these areas is particularly problematic.

Although growth in agricultural output has slowed in recent years, there are some significant exceptions to this general trend. For example, corn production has increased rapidly (5% per year from 1997 to 2007) as the introduction of winter corn and use of modern hybrids has spread rapidly. The area under corn also continues to expand, even in the states that typically have grown little if any corn such as Karnataka and Andhra Pradesh in southern India. Much of the crop was used as feed in the flourishing poultry sector in these southern states. Beginning in the 1980s, the production of *boro* rice also increased markedly, especially in the eastern part of the country. This was further enhanced by the spread of hybrid rice, which offers significant yield advantages (up to two metric tons per hectare) over conventionally bred varieties. The northern states have had no significant spurt in productivity growth, but they have maintained their comparatively high yields, with impressive improvement in the grain quality of rice. Yields have not improved in the pulses at the aggregate level but crop duration has been reduced, particularly in pigeon peas and chick peas, which has extended their reach into several non-traditional areas. The spread of Bt hybrids has improved yields in cotton. Similarly, farmers' access to improved varieties of vegetable seeds has led to increased production in the eastern, southern, and hill states characterized by predominantly small farms. All of these developments, among others, have contributed to the growth of Indian agriculture.

3.3. Partial and Total Factor Productivity Trends

Crop growth performances clearly show that the relative roles of area expansion and yield growth varied among crops. As a general rule, yield growth contributed more than area expansion to the growth in output for most crops, with the exception of cotton during the 1990s when yield growth was negative (Table 11.6). However, yield growth for all principal crops taken together slowed from an average of 2.56% per year during the 1980s to 1.33% per year during the 1990s, and the same pattern held true for most of the crops. The growth in crop yield, especially of coarse cereals and non-food grains, showed signs of recovery in more recent years. Cotton yields continued to decline during the 1990s, but development of hybrid cotton varieties, better pest management practices, and the introduction and rapid adoption of Bt cotton led to a rapid turnaround, with double-digit growth in yield and production after 2000.

Although yields have tended to increase over time in most of the states, and for all of India, there remains large spatial (state) variation in crop yields. The states with the highest productivity measured in terms of net state domestic product (measured in rupees [Rs] per hectare of total cropped area in the state in the year 2007-08) are Kerala (Rs 74,600/ha), West Bengal (Rs 69,000/ha), Tamil Nadu (Rs 64,200/ha) and Andhra Pradesh (Rs 56,400/ha).

A number of studies on total factor productivity (TFP) growth in Indian agriculture, and an assessment of the factors explaining those changes, have been carried out (Table 11.8). They clearly show evidence of robust growth in partial factor productivity and TFP as major drivers of output growth in the crop sector during the 1980s. Estimates of various studies show that the average rates of growth in TFP in the agricultural sector, including livestock, ranged from 0.90% to 2.29% per year during the 1980s and 1990s (Table 11.8). However, the reported rates of growth in TFP vary considerably in terms of the methodologies, time periods, and data series used. None of the studies reports TFP growth for India after the latter half of the 1990s. In addition, little research explores whether the source of growth is technical change or purely gains in efficiency. However, the study by Kalirajan and Shand (1997), following a frontier production function approach, found that during the 1980s much of the slowdown in the TFP con-

Table 11.8. Summary of total factor productivity studies of Indian agriculture

			Total Factor Productivity	
Author(s)	Commodity	Period	Annual Growth	Share of TFP Growth[a]
			(percent per year)	(percent)
Evenson, Pray, and Rosegrant 1999	Crops	1966-76	1.40	50.2
		1977-87	1.05	48.8
Fan, Hazell, and Thorat 1999	Crops and livestock	1980-89	2.52	66.5
		1990-94	2.29	72.2
Coelli and Rao 2003	Crops and livestock	1980-2000	0.9	-
Kumar, Kumar, and Shiji 2004	Aquaculture	1992-98	4.4	71.7
	Marine	1987-98	2.0	48.8
Birthal et al. 1999	Livestock	1951-70	-0.04	-
		1970-80	0.93	33.2
		1980-95	1.79	45.0
Joshi et al. 2003	Rice (IGP)	1980-90	3.5	-
		1990-99	2.1	-
	Wheat (IGP)	1980-90	2.4	-
		1990-99	2.1	-

Source: Compiled from NAAS (2009).
[a]Indicates share of respective output growth attributable to growth in TFP.

tribution to output growth could be attributed to low rates of technological progress, together with gradual improvements in technical efficiency, but the output growth in the sector had become increasingly dependent on input growth.

As with crop yields, the measured rates of growth of TFP varied markedly throughout the country. For example, the Indo-Gangetic Plains witnessed impressive TFP growth in rice (3.5% per year) and wheat (2.4% per year) during the 1980s, thus underscoring the key role of technology in making the country food secure (Joshi et al. 2003). However, the study showed deceleration in TFP growth, especially for rice, during the 1990s, thus raising concerns about the sustainability of the rice-wheat cropping system. Kumar, Kumar, and Mittal (2004) also found that TFP grew more rapidly in the agricultural sector during the 1980s relative to the 1990s in the Indo-Gangetic Plains. By way of contrast, TFP in the livestock sector grew little before the 1970s. The sector saw the pace of productivity growth picking up during the 1980s when TFP growth reached nearly 1.8% per year, contributing 45% to total output growth (Birthal et al. 1999). In the fisheries sector, TFP growth was much higher in aquaculture as compared to marine production during the 1990s. The TFP index for aquaculture grew by 4.4% annually and accounted for more than 70% of the growth in aquaculture production (Kumar, Kumar, and Shiji 2004).

In an effort to explain the rate of productivity growth, Kumar, Kumar, and Mittal (2004) identified research, extension, literacy, and infrastructure as the most important sources of TFP growth in the Indo-Gangetic Plains. Extension accounted for about 45% of the TFP growth, followed by public research (36%) and literacy (10%). Investment in agricultural research and development (R&D) also made a significant contribution to Indian productivity growth according to Evenson, Pray, and Rosegrant (1999) and Fan, Hazell, and Thorat (1999).

4. SOURCES OF AGRICULTURAL GROWTH

4.1. Public Investment in Agriculture

Public investment in agriculture targeted to infrastructure and the provision of farm services has been an important element of agricultural policy in India. The experiences of the green revolution showed that a strategy of strong public support for agriculture has paid rich dividends. Initially most public investment in India was directed toward irrigation infrastructure, particularly surface irrigation. Investment eventually extended to such areas as R&D, public provision of critical inputs like seed and fertilizer, rural electrification, animal health, and agricultural product markets. Empirical evidence supports a positive correlation between public and private investment (Roy and Pal 2002). This positive correlation could be seen in the development of groundwater irrigation in India, whereby public investment in rural electrification encouraged farmers to invest in tubewell installation. This led to rapid growth in the adoption of groundwater irrigation, beginning especially in northwest India and then spreading to other parts of the country.

The broad trends in public investment constitute three phases during the post-independence period. First, although investment has increased significantly over the years since independence, it rose rapidly during the food crisis of the 1960s and 1970s. Second, driven by the objective of food security, the government invested heavily in agriculture during the early 1970s, and this level was sustained during the subsequent period. Third, spurred by a slowdown in agricultural growth beginning in the mid-1990s, the government once again stepped up its investment in agriculture, leading to a spike in investments during the first decade of this millennium (Figure 11.2). An upward trend in private investment commenced in the mid-1970s and a sharper rise was further witnessed in the 1990s.

The pattern of public investment has changed significantly over time. It became more broad based (spatial coverage and items of investment), and the share of centrally funded and state-operated schemes also rose over time. The rising

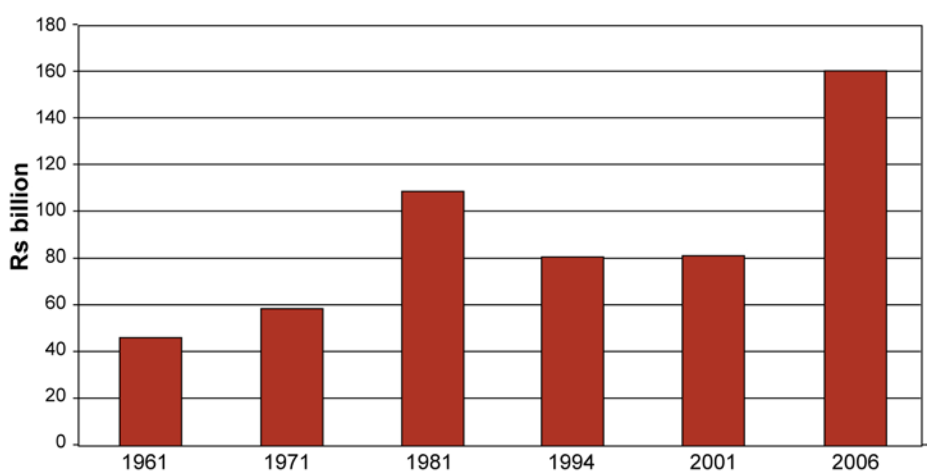

Figure 11.2. Gross capital formation in agriculture from the public sector, 1999-2000 prices
Source: CSO (various years).

burden of subsidies eroded the government's ability to invest in agriculture, and there is an emerging consensus that these subsidies should be rationalized and the resulting savings diverted to public investments in the sector.

4.2. Irrigation

Most of the public investment in agriculture has been for development of irrigation infrastructure, mainly surface irrigation. But investment in rural electrification has also expanded and in turn stimulated investments into tube-well technologies, thereby affecting crop productivity. Studies indicate that the increased use of irrigation and the spread of high-yielding crop varieties have been major sources of growth in Indian agriculture. This trend has continued, but a number of issues have emerged requiring immediate attention. Per capita demand for water is projected to increase markedly, but without commensurate increases in its availability. It is estimated that the latent demand for water for various purposes will far exceed availability by 2050, and other sectors (urban domestic, industries, etc.) will compete with agriculture for water (NAAS 2009).

The first major issue for agriculture is the optimal use of surface irrigation (canal and tank irrigation) and increased technical efficiency in water use, which is currently estimated at about 25% to 35% in most irrigation systems (Planning Commission 2008). Substantial investment is needed for upgrades in irrigation infrastructure to reduce water losses. In addition, better distribution of irrigation water and recovery of irrigation charges are envisaged through participation of farmers in water user associations. These associations, in partnership with irrigation departments, can effectively maintain irrigation channels, manage water distribution at the farm level, and recover costs from member farmers. Successful joint management has yet to materialize, especially in terms of cost recovery.

The second major issue is improvement of water use efficiency through water-saving technologies like drip and sprinkler irrigation and conservation agricultural practices (zero tillage and aerobic rice). These technologies can reduce pressure on groundwater irrigation. Technological advancements are also needed to address poor quality water. A large part of India (northwest plains and coasts) is facing the problem of salt-affected water, and any technological advancement to reclaim and use this and other poor quality water will help sustain crop productivity in these regions. Besides technological options, policy and institutional options are needed to control groundwater depletion. The state of Punjab has enacted a ban on summer paddy, a crop that is transplanted in May, while Haryana has withdrawn price supports for summer paddy. There is also a move to shift to volumetric pricing of electricity for tubewell irrigation to control water extraction.

4.3. Agricultural R&D

The creation of a strong R&D system for agriculture has been an important policy goal of the Government of India. As a result, India is one of the few developing countries to sustain a positive rate of growth in real public investment in agricultural research. Research funding increased from 0.3% of agricultural GDP in 1971 to more than 0.5% in 2004 for both agricultural research and education, and all signs point to a continuation of this uptrend. India has seen two structural changes in funding and the use of this investment. First, the central government's share of funding has risen over time and now accounts for nearly half of total funding. Second, allocation to the dryland regions, for such things as natural resource management research and livestock development, has been increasing. The only region that continues to receive low investment is the eastern region, where funding by state governments is very low. Another noteworthy trend is that an increasing amount of funding is being allocated competitively, thus opening up access to funding to a broader set of public institutions (Pal and Byerlee 2003).

Besides raising the amount of public investment, the government, through the Indian Council of Agricultural Research (ICAR), has addressed organizational issues to enhance research effectiveness. The government has made a number of policy reforms recently, and the focus is now on accelerating the pace of implementation of these reforms. Highlights of these institutional reforms are

- strengthening the monitoring and evaluation of institutes and their programs and the use of information communication technology in research management;
- strengthening the research and development continuum through stronger linkages between research, technology transfer, and end-users; and
- managing intellectual property for rapid transfer of technology and fostering partnership among actors in R&D, especially between the public and private sectors.

Management of intellectual property rights (IPRs) represents a major shift in R&D, and these measures warrant further elaboration. India has put in place legislation to comply with the agreements related to IPRs under the World Trade Organization. Among these, protection of plant varieties, farmers' rights, and other innovations are of great significance to agriculture. ICAR has established a unit for IPRs management and has developed IPRs policy and guidelines for their implementation. The main elements of the policy are as follows:

- ICAR will seek and maintain ownership rights for all intellectual properties, such as plant varieties, process and product innovations, research data, computer programs, designs, and publications, generated by its institutes.
- ICAR will encourage its institutes to use IPR policy to accelerate technology flow to farmers, promote competitive markets for innovations/ technologies, especially in the private domain, and promote inclusive and sustainable agricultural growth.
- ICAR will offer incentives for innovation by sharing the benefits of research with researchers, entrepreneurs, and farmers.

With the establishment of the Protection of Plant Varieties and Farmers' Rights Act, a large number of extant and new varieties have been registered for protection. These varieties are being commercialized through partnership with state and private seed agencies. In addition, efforts are being made to conserve and protect genetic resources through in situ and ex situ measures. ICAR also encourages conservation of animal and fish genetic resources by registering species.

Networking and partnership for pooling of resources, expertise, and skills are important for generating synergies in research. This concept is promoted through a number of network projects involving ICAR institutes and other institutions. These projects are in high-priority research areas and complement the network of coordinated research projects in India.

The private sector role in many facets of agriculture has expanded, from supplying inputs (seeds, fertilizers, pesticides, animal feed, etc.), to product marketing and value chain development, to commercialization of technologies. For instance, the private sector provides 58% of total commercial seeds (Planning Commission 2008). The non-profit private sector, such as research foundations and civil society organizations, is also active in agricultural development, including R&D. All of these organizations will increasingly depend on public R&D organizations for a variety of support. ICAR has instituted initiatives to foster partnerships with private and civil society organizations. These efforts have been accelerated to promote partnership with the private sector under externally funded projects of the World Bank. An emphasis on commercialization of technologies is also encouraging partnership with the private sector, whereby public research institutions license their technologies to the private sector on a non-exclusive basis.

4.4. Use of Inputs

Table 11.9 illustrates the rapid uptake of new seed and fertilizer technology during the green revolution. Average per hectare use of fertilizer doubled in every decade from 1971 to 1991. Subsequently the rate of increase was not as high but was still impressive; in fact, in absolute terms the increase in the application rate of fertilizer during the 1990s equaled that of the 1970s. Currently, the average rate of fertilizer application is 113 kg/ha, which is still much below the recommended level. Another notable feature of fertilizer use is that there is considerable interregional variation, especially in irrigated areas. For example, in the Punjab, average fertilizer use is as high as 209 kg/ha. Nitrogen fertilizer is most commonly used by farmers, with a high imbalance in the use of other plant nutrients (e.g., phosphorus and potassium). Recently, the government has provided price subsidies to encourage a more balanced use of plant nutrients. Similar trends are echoed in the use of other purchased inputs, and this is somewhat reflected by the growth in institutional credit to agriculture.

Private investment in farm mechanization and tubewell irrigation has been another major driver of economic growth. There were only 148,000 tractors in India in 1971 (Table 11.9). The number rose to more than two million tractors by 2006. Similarly, the share of cropped area irrigated by tubewells increased from 16.6% in 1971 to 26% in 1981, and rose further to 44% in 2006. This investment in farm mechanization and irrigation has not only contributed to an increase in crop productivity but also has helped raise the intensity of cropping. Another advantage of the expansion of tubewell irrigation has been a greater

Table 11.9. Inputs use in Indian agriculture, 1971-2006

	1971	1981	1991	2001	2006
Fertilizer use (kg/ha)	16.5	34.24	69.84	91.13	113.26
Number of tractors (000)[a]	148.2	275.9	738.4	1,221.8	2,361.2
Share of tubewells in irrigated area (%)	16.63	26.2	38.42	40.84	43.86
Quality seed distribution (000 tons)	n.a.	450	575	918	1,550
Institutional credit (Rs/ha)	53.58	232.42	631.39	3,261.40	10,544.45

Source: MoA (various issues).

[a]Data pertain to 1972, 1977, 1987, 1992, and 2003, respectively.

stability in crop yields, thereby reducing the size of government interventions to maintain buffer stock. However, as with fertilizer use, the most disquieting feature of farm mechanization and irrigation is that these developments have been mostly concentrated in the northwestern region of the country (in states such as Punjab and Haryana). This has led to charges of over-investment in mechanization (which results in a higher cost of production and lower farm income), and overuse of irrigation water in this region has led to questions about the long-term sustainability of the rice-wheat production system in this part of India.

One recent development concerning input use and crop establishment practices has been the adoption of resource conservation agriculture, mainly in the rice-wheat system. The most widely adopted technology is direct sowing of wheat after paddy in untilled fields, which is known as zero tillage. Estimates place more than three million hectares under zero-till wheat in 2005. The main advantages of this technology are (a) tractor fuel savings and a reduction in carbon emissions; (b) savings in the use of irrigation water, mainly groundwater; (c) carbon sequestration and low or delayed carbon dioxide emissions; and (d) a reduction in herbicide use (Laxmi, Erenstein, and Gupta 2007).

4.5. Price Support and Terms of Trade

Government interventions in providing price support to farmers and improving the physical and economic access of poor consumers to food have been important elements of agricultural price policy in India since 1965 when the Commission for Agricultural Costs and Prices (CACP, formerly the Agricultural Price Commission) was established. The government procures food grains at a predetermined price called the Minimum Support Price announced by the government on the recommendation of the CACP. Although the price is announced for two dozen commodities, there is procurement of only a few select commodities (rice and wheat). The commodities are distributed to the public at a price lower than market price through fair price shops managed by the state governments. Part of the stock is used as a buffer to reduce temporal variations in availability of food grains.

These government interventions have been successful in improving food access and ensuring a fairly stable price environment. This in turn has encouraged farmers to adopt new technology and use modern inputs and crop practices and thereby helps improve crop productivity, which in turn strengthens national food security, which is a significant impact of agricultural price policy (Acharya

1997). This, coupled with other interventions, such as development of market infrastructure and regulation of markets to control exploitative practices of traders, has helped in providing incentives to farmers and reducing margins in the market. This effect has been so significant that some observers have charged that the government has discouraged private corporate participation in food grain markets (Chand 2003). However, because government operations are confined to so few food grain surplus states, there is tremendous opportunity for the corporate sector to participate in food grain trade.

With the demand side of the Indian food economy developing rapidly, a number of initiatives have been enacted recently to attract corporate investment in agricultural marketing. An act prohibiting direct purchase of produce from farmers by traders was relaxed, and model legislation was prepared in 2003 to allow participation of the corporate sector. Since then, most states have adopted this legislation, and some private firms are directly procuring produce from farmers. Some firms have established terminal markets,[4] mainly for high-value commodities like fruits and vegetables, while others are procuring produce from farmers through dissemination of market information using informational technology (for example, the e-Choupal program of ITC Limited). Another related development has been the practice of contract farming, in which a processing or agricultural company enters into a contract with farmers to purchase produce at a pre-agreed price. The company also provides crop information, inputs on credit, and other support for better yields and produce quality. Although there have been some instances of both companies and farmers failing to comply with contracts, the arrangements have worked well, especially for high-value commodities (Joshi, Gulati, and Cummings 2007).

In addition to these major policy changes, several other market reforms initiated by the government have improved the discovery and stability of agricultural prices. These reforms relate to relaxation of control over movement and storage of food grains and of futures markets, attracting investment in market infrastructure and agro-processing, and liberalization of trade. Although the impact of these reforms will not be clear for some time, all signs point to improvement in incentives for farmers. The domestic terms of trade (i.e., farm output to input prices) did not favor agriculture during the 1980s but started to improve in the early 1990s. Also,

[4]These are professionally managed enterprises that provide complete market services to farmers at their door step and operate in hub-and-spoke format.

domestic agricultural commodity prices have remained much more stable than international prices, which have shown a high degree of volatility. A stable price environment and better incentives will encourage farmers to invest in productivity-enhancing inputs and practices and thereby contribute to agricultural growth.

5. FUTURE CHALLENGES AND STRATEGY

Notwithstanding the impressive performance of Indian agriculture in the past, there are a number of challenges which, if not addressed, in time may hold back not only the agricultural sector but also the entire Indian economy. We have seen this in the recent past when impressive economic growth but moderate agricultural growth puts upward pressure on food prices and exacerbates rural-urban income disparities. The first and foremost challenge is to attain and sustain a target growth of 4% per year in agricultural output as envisaged by the Planning Commission. This growth should be inclusive and geographically widespread in terms of participation of smallholders and those in marginal production environments. Most of this growth will be realized through higher productivity through the application of modern technology. However, participation of smallholders will also entail institutional innovations to enable aggregation of their production and to link them with markets.

The second most important challenge is to address the vulnerability of Indian agricultural production. Currently, two-thirds of agricultural lands are rain-fed and subject to the vagaries of weather and other vulnerabilities. This vulnerability is further accentuated by the degradation and depletion of natural resources, which are also seen in irrigated production environments (NAAS 2009). A two-pronged strategy is needed. First, the severity and long-term implications of these challenges are not well understood by farmers. Therefore, a national program should be created to educate farmers about long-term sustainability issues. Second, farmers should be empowered with the appropriate technologies to address sustainability and vulnerability concerns. This should be backed with policy interventions to manage risk and strengthen social safety nets.

Climate change is a recent challenge, and its likely impacts are becoming better understood and local responses are evolving. Responses include a continued partnership with the international community to assess the challenge as the events unfold and further work on adaptation and mitigation strategies consistent with local realities. A considerable amount of resources will be needed for technological solutions and their adaptation by farmers and other stakeholders.

Finally, development of human capital is the key to innovation and acceleration of agricultural growth. The government should invest more in building this capacity within various government departments, development agencies, and with farmers. Efforts to accelerate the flow of technologies to farmers and improve their skills and ability to innovate will go a long way toward strengthening the long-term productive capacity of Indian agriculture. But this requires the mobilization of resources in the public and private sector, ensuring the participation of farmers, and encouraging technology-led solutions.

6. CONCLUSION

Despite the impressive performance of Indian agriculture during the period of the green revolution supported by significant public investments and associated institutional developments, agriculture has failed to meet its growth target over the last decade. However, if we exclude some years of abnormally adverse weather (specifically the years 2002-03 and 2004-05), an adjusted annual growth rate of more than 3% per year was sustained over the period 1997-98 to 2008-09. This is a notable achievement, especially considering India's severe resource and production environment constraints. The trend toward commercialization and diversification of agriculture is increasing, and most of the growth in output in recent years was realized through productivity growth. Given the increasing demand for high-value commodities, as well as the need to produce more food grains to feed a still growing population, the goals of food security and diversification for high-value agriculture should be pursued through technological interventions. An increase in the productivity of food grains would enable land to be used to grow high-value crops like fruits and vegetables without compromising domestic food production. Continued government support for agricultural R&D and higher public investment in infrastructure are welcome steps in increasing productivity. Encouraging business interests in food and agriculture and fostering institutional innovations to improve smallholders' access to technology are current policy thrusts. A supportive policy environment with well-structured incentives can be a major driving force to promote innovation in agriculture, and lessons from any localized successes in this regard also need to be well understood and replicated. Enhanced efforts to sustain India's natural resources, provide productive infrastructure through better technological and institutional solutions, and develop human capital capacity will help accelerate the country's agricultural growth.

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CHAPTER 12

Indonesia: From Food Security to Market-Led Agricultural Growth

Keith O. Fuglie

1. INTRODUCTION

During the latter half of the twentieth century, rising output per hectare replaced expansion of cropland as the predominant source of agricultural growth in most of the world (Hayami and Ruttan 1985). This transition from agricultural extensification to intensification was particularly noticeable in Asia, where population density is relatively high and land scarcity is acute. Indonesia is something of a special case, possessing both very densely populated, land-scarce agriculture on Java, and relatively land-abundant agriculture elsewhere on the large islands of Sumatra, Kalimantan, Sulawesi, and Papua. The country achieved considerable success in agriculture during the 1970s and 1980s through the diffusion of high-yielding varieties of food crops, although this source of growth appeared to stagnate by the early 1990s (Fuglie 2004). Meanwhile, land devoted to agriculture continued to expand, with virtually all new cropland coming from Indonesia's outer islands, and principally for tropical perennials like oil palm and cocoa. In this chapter, I examine the sources of agricultural growth in Indonesia over the 45 years from 1961 to 2006. I use a growth accounting method to examine how resource expansion, technologi-

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cal improvements, commodity diversification, and human capital contributed to growth in real agricultural output.

The approach used in this chapter builds on my earlier work (2004), which was the first to develop a Tornqvist-Thiel index of total factor productivity (TFP) for Indonesian agriculture. The present work expands commodity coverage to include cultured fisheries in addition to crops and livestock. Cultured fisheries, an increasingly important component of agriculture in many Asian countries, compete directly with crops and livestock for land, labor, feed, and other resources but have been largely ignored in assessments of agricultural productivity. In addition, this work includes improved data on agricultural cropland with more complete coverage of land planted to tropical perennials. Finally, the chapter develops a measure of labor force quality as a factor in production. In many developing countries in Asia, the rate of growth in the agricultural labor force has sharply declined or turned negative over the past several decades. However, labor force quality, in the form of higher literacy rates and universal primary education, has improved. Jamison and Lau (1982) compiled ample micro-level evidence to demonstrate the link between farmer education and agricultural productivity in developing countries; the present study accounts for the contribution of improvements in farmer education to productivity growth at the sector level.

The Tornqvist-Thiel indexes of output, input, and productivity are measures of changes in the real economy and avoid the index number bias arising from the use of fixed weights in input and output aggregation. Some previous studies of agricultural productivity in Indonesia have used agricultural gross domestic product (GDP) as a measure of output (Van der Eng 1996; Mundlak, Butzer, and Larson 2004), but GDP confounds quantity and price effects on output growth and thus may not reflect true changes in productivity. Other studies have estimated Malmquist TFP indexes for Indonesia using the Food and Agriculture Organization (FAO) output and input quantity data (Arnade 1998; Suhariyanto 2001; Coelli and Rao 2005). However, the FAO output measure is a Laspeyres index using a fixed set of international prices as weights to aggregate commodities and may result in biases if there are significant changes in relative prices or commodity mix over time (Fan and Zhang 2002). Moreover, the Malmquist index measure of agricultural TFP is sensitive to the dimensionality issue (e.g., the number of countries and input-output quantities included in the analysis) and may give implausible results (Lusigi and Thirtle 1997).

For this study I develop time series of output and input quantities and prices and use moving averages of revenue and cost shares to aggregate output and input quantities, respectively. Agricultural output is composed of 75 crop, animal, and fish commodities. The agricultural input index consists of 42 types of land, labor, capital, and intermediate inputs used in crop, livestock, and aquaculture production. The Tornqvist-Thiel TFP index is given by the ratio of aggregate output to input quantities, and thus TFP rises when the growth in the quantity of outputs exceeds the growth in the quantity of inputs. TFP is the residual component of growth after accounting for changes in factor inputs. It can be interpreted as a measure of the gain in efficiency with which inputs are used, including technological progress.

In the next section, I review the role of agriculture in Indonesia's economy and provide detail on changes in agricultural production and input use over time.

2. AGRICULTURE IN THE INDONESIAN ECONOMY

2.1. Agriculture's Contribution to GDP, Employment, and Trade

Indonesia is a Southeast Asian archipelago consisting of some 17,500 equatorial islands (6,000 inhabited) stretching in an east-west direction for over 5,000 kilometers. It has a land area of 1.83 million square kilometers supporting in 2005 a population of 221 million (the fourth-largest in the world), which was growing at about 1.4% per annum.

The extent of structural changes in the Indonesian economy between 1965 and 2005 is shown in Table 12.1. The population more than doubled over this period. Real GDP increased by about 10 times and real per capita income by about 480%. By 2005, Indonesia had a per capita income of $3,209 (2005 international dollars) and was classified by the World Bank as a lower-middle-income country. Large changes have occurred in the sectoral shares of GDP, with agriculture's share declining from 56% to 17%, accompanied by significant increases in the shares of the services sector (now the dominant sector with a 40% share in 2005); manufacturing (25%); and mining, oil, and gas (19%). Agriculture's share of total employment also declined, from nearly 70% in 1965 to 44% in 2005. It still remains the dominant sector of employment. While Indonesia's economy has become much more dependent on trade overall, agriculture's share in total merchandise exports fell from 57% to 20% between 1965 and 1975 but has fluctuated at around 20% since then.

Broad trends in the agricultural sector are shown in Table 12.2. Real agricultural GDP nearly tripled between 1961-65 and 2001-05 and averaged $95 bil-

Table 12.1. Agriculture in the Indonesian economy since 1965

Indicators	1965	1975	1985	1995	2000	2005
Population (millions)	105	133	163	193	206	221
Per capita income (2005 international dollars)	663	1,032	1,616	2,816	2,724	3,209
Gross domestic product (billions of 2005 international dollars)	69	137	263	543	562	708
Share of GDP (percent)						
Agriculture	56	30	23	17	17	17
Services	31	36	41	41	37	40
Manufacturing	8	10	16	24	25	25
Mining, Oil, and Gas	4	24	20	18	21	19
Share of employment (percent)						
Agriculture	69	62	55	44	45	44
Industry	7	8	13	18	18	18
Services	24	30	32	48	37	38
Trade as share of GDP (percent)	11	45	43	54	71	64
Ag share of total merchandise exports (percent)	57	20	21	27	16	18

Sources: WDI Online, except for agricultural exports. Agricultural exports include crop, animal, fish and seafood, wood and plywood products and are from the UN Comtrade Database.

lion (2005 international dollars) per year during 2001-05, making Indonesia the fifth-largest agricultural producer in the world (WDI Online). Food crops (particularly rice) constitute the largest component of agricultural output, but food crops' share of total output has gradually declined over time.

Rice production dominates the food-crop sector, and production increased four and a half times between 1961 and 2005, mainly as a result of yield increases. Adoption of modern varieties and fertilizers played an important role in securing higher yields. Rice remains the staple food, and national self-sufficiency carries great political significance. Estate crops, such as rubber, oil palm, sugarcane, and cacao, are becoming an increasingly important component of Indonesia's agricultural sector. Livestock and aquaculture production are also growing rapidly in response to the rising demand for animal protein, commensurate with rising per capita incomes.

According to the Indonesian Agricultural Census (done every 10 years since 1963), the number of farm households steadily increased between 1963 and 2003 in both Java and elsewhere, reaching a total of nearly 25 million households in 2003. According to census figures, average farm size has been decreasing in Indonesia, to about 0.4 hectares per household in Java and 1.3 hectares

Table 12.2. The structure of Indonesian agriculture, 1961-65 to 2001-05

Indicators	1961-65	1971-75	1981-85	1991-95	2001-05
	(annual average over period)				
Agricultural GDP (millions of 2005 international dollars)	35,987	42,311	55,271	83,567	95,268
Share of Ag GDP (percent)					
Food crops	64.8	59.9	61.8	55.8	51.1
Nonfood crops	17.4	17	15.7	16.6	14.9
Livestock	6.7	7.1	9.9	11.4	12.7
Fisheries	8	5.7	6.8	9.3	15
Forestry	3.1	10.3	5.8	6.7	6.3
Rice output (million tons of paddy)	12.4	21.2	35.8	47.5	52.5
Rice output per capita (kilograms milled rice)	97.6	110.5	154.6	165.0	157.6
Rice yield (tons per hectare)	1.8	2.5	3.8	4.4	4.5
Total crop land (million hectares)[a]	17.6	18.9	26.0	32.2	38.5
Java and Madura	9.0	8.8	7.0	7.1	7.0
Other islands	8.6	10.0	19.6	25.1	31.5
Number of farm households (millions)	12.2	14.4	19.5	21.7	24.9
Java and Madura	7.9	8.7	11.6	11.8	13.6
Other islands	4.3	5.7	7.9	9.9	11.3
Average size of farm[b] (hectares per farm)	1.1	1.0	1.0	0.8	0.8
Java and Madura	0.7	0.6	0.6	0.5	0.4
Other islands	1.7	1.5	1.6	1.2	1.3

Table 12.2. Continued

Indicators	1961-65	1971-75	1981-85	1991-95	2001-05
	(annual average over period)				
Agricultural wage (kilograms of rice per day)[c]	1.1	2.7	3.7	4.1	5.9
Agricultural exports % of Agricultural GDP	n.a.	n.a.	n.a.	24	37
Agricultural imports as % of Agricultural GDP	n.a.	n.a.	n.a.	11	14

Sources: Agricultural GDP, shares of Ag GDP, and agricultural trade are from BPS *Statistical Yearbook of Indonesia*. Rice output, livestock numbers, rice yield, and fertilizer use from FAOSTAT. Cropland, irrigated cropland, and agricultural wages are from Van der Eng 1996. Farm numbers and landholdings are from Agricultural Census for census years 1963, 1973, 1983, 1993 and 2003 as reported in Fuglie and Piggott 2006.

n.a. = not available.

[a]Includes land in annual (paddy, garden and upland crops) and perennial (estate) crops.

[b]Represents farm household landholdings and does not include land held by large estates.

[c]Represents wages of male workers on Java (rupiah per half-day of work divided by the farmgate price of rice).

per household outside of Java. The landholdings reported by the Agricultural Census include land in annual crops but exclude land in estate crops (although most estate crops are grown by smallholders), so these figures underestimate average agricultural landholdings per household.

Many household members that depend on agriculture do not own land of their own (or have only very small holdings) and work as laborers on other farms or corporate estates. Daily agricultural wages, measured in terms of the amount of rice afforded, rose more than six-fold between 1961-65 and 2001-05. Part of this rise in real wages can be attributed to Indonesia's success in raising its domestic rice supply, making rice more plentiful and cheap. Part of the rise in real agricultural wages is also due to growth in non-farm wages and a rising opportunity cost of labor.

Since the 1990s (earlier data are not available), trade in agricultural commodities has played an increasingly important role for Indonesia. The share of exports as a percentage of agricultural GDP rose from 24% in the early 1990s to 37% in 2001-05 while the value of agricultural imports rose from 11% to 14% of agricultural GDP (Table 12.2). Table 12.3 gives three snapshots (1976, 1996, and 2006) of the changing composition and value of major agricultural trade products. By 2006, oil palm products had replaced plywood and rubber as the dominant agricultural export. Fish, shrimp, cocoa, and coffee were other major export earners. For food and agricultural imports, in the 1960s Indonesia was the world's largest importer of rice, but by 2006, wheat, sugar, cotton, and feed grains (corn, soybeans, etc.) had become far more significant import items than rice. Indonesia enjoys a positive trade balance in food and agricultural products.

2.2. Changing Composition of Agricultural Outputs and Inputs

Table 12.4 describes the growth and composition of agricultural output and input use in Indonesia. Output figures are measured in terms of millions of tons of "rice equivalents" produced per year, averaged over a five-year period. To obtain rice equivalents, the output of each commodity is multiplied by its price relative to that year's price of (unmilled) rice and then aggregated across commodities (in other words, the price of paddy rice is a *numéraire* price). Thus, during 2001-05, Indonesian farmers produced a gross output of 143.6 million tons of rice equivalents annually, of which 52 million tons was rice itself. Oil palm was the second most important commodity, with gross production of palm oil and palm kernel oil together worth an equivalent of 10 million tons of rice. The importance of oil palm to the Indonesian agricultural sector is relatively new,

Table 12.3. The composition of Indonesia's agricultural trade

1976		1996		2006	
Major Ag Export Items	**Value (mil. US$)**	**Major Ag Export Items**	**Value (mil. US$)**	**Major Ag Export Items**	**Value (mil US$)**
Wood & plywood	787	Plywood	3,595	Palm & palm kernel oil	5,434
Natural rubber	532	Natural rubber	1,920	Natural rubber	4,322
Coffee	238	Palm & palm kernel oil	1,061	Plywood	1,507
Palm & palm kernel oil	136	Shrimp, fresh & frozen	851	Shrimp, fresh & frozen	1,087
Fish, fresh & frozen	124	Fish, fresh & frozen	493	Cocoa beans & butter	798
Tea	57	Coffee	595	Coffee	589
Pepper (Piper spp.)	47	Fruits & vegetables	376	Fish, fresh & frozen	490
Tobacco products	40	Cocoa beans & butter	345	Fruits & vegetables	472
Fruits & vegetables	18	Coconut oil & copra	340	Coconut oil & products	355
Cassava	11	Tobacco products	220	Tobacco products	340
		Tea	112	Tea	135

1976		1996		2006	
Major Ag Import Items	**Value (mil. US$)**	**Major Ag Import Items**	**Value (mil. US$)**	**Major Ag Import Items**	**Value (mil US$)**
Rice	450	Wheat & wheat flour	1,055	Wheat & wheat flour	959
Sugar	111	Cotton	980	Sugar	641
Cotton	84	Rice	766	Cotton	620
Wheat & wheat flour	75	Sugar	513	Fruits & vegetables	570
Cloves	42	Soybeans	252	Dairy products	569
Dairy products	39	Fruits & vegetables	250	Soybeans	300
Soybeans	20	Live animals	205	Corn	277
Tobacco products	13	Dairy products	194	Other animal feeds	236
Corn	9	Tobacco products	181	Tobacco products	191
		Corn	133	Rice	133
		Other animal feeds	126	Live animals	117

Source: UN Comtrade Database.

Table 12.4. Agricultural production and input use, 1961-65 to 2001-05

Production/inputs	1961-65	1971-75	1981-85	1991-95	2001-05
	(average annual quantity over period)				
Crop, animal & fish outputs, total (in million tons of rice equivalents)	28.42	54.57	81.53	117.45	143.60
Food crops, all	16.34	28.63	45.04	62.03	66.97
Rice, paddy	12.39	21.18	35.77	47.50	52.47
Cassava	1.47	2.52	2.51	3.91	2.54
Corn	1.14	1.99	2.56	4.02	7.13
Horticultural crops, all	3.15	6.08	8.22	12.64	19.30
Fruits, all	1.82	3.74	5.17	5.35	7.29
Vegetables, all	1.33	2.34	3.05	7.29	9.09
Nonfood crops, all	5.19	12.81	15.23	20.27	31.98
Oil palm	0.07	0.15	0.49	1.79	10.25
Coconut	1.25	5.35	4.78	5.51	6.52
Rubber	1.57	2.09	2.31	3.90	5.46
Sugarcane	0.40	1.82	2.87	3.92	2.85
Cocoa	0.00	0.01	0.07	0.47	1.84
Animal products, all	1.86	4.17	8.55	13.80	13.63
Meat	1.43	3.47	6.92	11.42	10.63
Milk and eggs	0.38	0.64	1.56	2.30	2.89
Fish products, all	1.88	2.60	4.48	8.71	11.72
Capture (marine & inland)	1.73	2.38	4.04	7.76	10.35
Aquaculture (marine & inland)	0.15	0.22	0.44	0.95	1.27

Table 12.4. Continued

Production/inputs	1961-65	1971-75	1981-85	1991-95	2001-05
	(average annual quantity over period)				
Agricultural inputs (in given units)					
Agricultural labor (million workers)	28.64	31.71	37.67	46.14	50.72
Cropland (million hectares)[a]	17.55	18.85	25.87	32.25	38.45
Irrigated cropland (percent)[b]	15.24	16.15	18.06	22.66	23.31
Animals (million head of cattle equivalents)[c]	14.00	13.59	18.41	30.99	33.15
Fertilizer (kilograms per hectare)	6.90	22.70	64.30	76.30	85.60
Tractor horsepower/1000 ha of cropland	2.91	5.89	7.42	20.34	35.11
Aquaculture area (thousand hectares)	293	292	328	503	728

Sources: Output quantities are from FAOSTAT. Output quantities are converted into "rice equivalents" using local wholesale prices from FAOSTAT, BPS *Statistical Yearbook of Indonesia*, and MOA. Agricultural labor, animal stocks, and fertilizer estimates are from FAOSTAT. Cropland, irrigated cropland, the number of tractors and aquaculture area are from BPS *Statistical Yearbook of Indonesia*. Tractors include 2-wheel and 4-wheel tractors.

[a]Includes land in annual (paddy, garden, and upland crops) and perennial (estate) crops.

[b]Represents percentage of cropland planted to annual crops receiving irrigation at least part of the year.

[c]Sum of cattle, buffalo, horses, small ruminants, pigs, and poultry aggregated using Hayami and Ruttan (1985) weights.

having increased by a factor of six just over the last decade. Cocoa, horticultural crops, animal products, and aquaculture were other fast-growing components of the agricultural sector. Rice production grew rapidly during the green revolution decades of the 1970s and 1980s, but growth in rice and other food crop production slowed after 1990.

In the latter half of the twentieth century, Indonesia added significant amounts of land, labor, and other inputs to agriculture (Table 12.4). Cropland expanded by an average of 1.4% per year during 1961-2005 and was still growing by more than 1% per year in the 2001-05. Figure 12.1 shows trends in cropland for densely populated Java and for other islands since 1961. While Java constitutes only 7% of Indonesia's land area, it holds about 60% of the nation's population and in 2000 had a population density of 856 persons/km^2 (BPS, *Statistical Yearbook of Indonesia*). Virtually all of the expansion of cropland since 1961 has occurred outside of Java, especially on the islands of Kalimantan, Sumatra, and Sulawesi. Nationally, agricultural cropland expanded to 38 million hectares by 2005. Irrigation had been extended to 4.8 million hectares and covered about 60% of the wetland rice (*sawah*) area, or about 23% of total cropland. Land resources devoted to aquaculture (brackish and freshwater ponds) grew

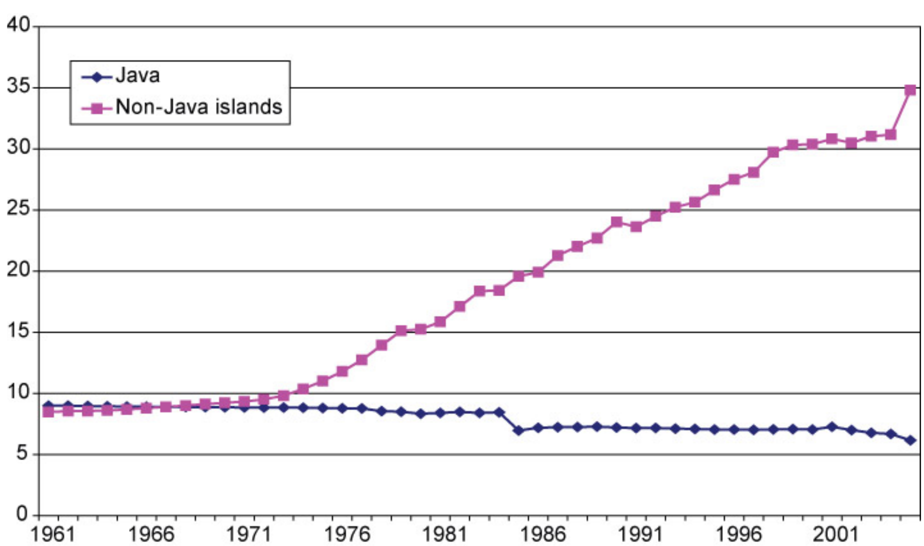

Figure 12.1. Agricultural cropland in Indonesia (million hectares)

Source: BPS *Statistical Yearbook of Indonesia*, supplemented by data from Van der Eng (1996) and MOA.

from 0.3 million hectares to 0.7 million hectares between 1961-65 and 2001-05, with expansion of ponds accelerating over time. But the largest increase in cropland was for estate crops. The new estimates of area planted (including area in immature trees) show that estate cropland grew from 4.6 million hectares in the early 1960s to over 18 million hectares by 2006. By the late 1990s, oil palm had replaced rubber and coconut as the dominant estate crop and by 2006 accounted for about one-third of the total area in estate crops. About 14 million hectares out of a total of 18 million hectares in estate crops were held by smallholders with 1-2 hectares of estates and the rest by large private and state-owned plantation companies (MOA).

FAO reports that the number of persons employed in agriculture in Indonesia grew from 28 million to 51 million persons between 1961-65 and 2001-05 and was still growing by about 0.6% per year in 2001-05. However, many of these persons only work part-time in farming, earning a large share of their household income from non-farm activities. In densely populated Java, time spent in farming per agricultural worker probably declined over time, as census data has shown that the share of non-farm income in the total income of farm households has risen (Booth 2002). However, outside of Java, area in crops expanded more rapidly than the agricultural labor force so that area farmed per worker rose (Van der Eng 1996). In these regions, average time spent farming per worker may have increased, as mechanization levels remained very low. This is where most of the expansion in estate crop production occurred, and, unlike annual crops for which labor demand tends to be seasonal, labor required in tree-crop production is often more evenly spaced throughout the year. Oil palm bunches, for example, ripen continuously throughout the year and need to be selected and picked manually when ripe. It is difficult to say how per capita labor allocated to agriculture may have trended nationally, but it is worth noting that cropland per capita grew, from about 0.8 ha per person in 1960-65 to 1.1 ha per person in 2000-05 (Table 12.2).

Use of manufactured inputs used in agriculture, such as fertilizer, machinery, and animal feed, grew rapidly in the 1970s and 1980s but from almost negligible initial levels. Fertilizer use increased by 11% per year during 1961-1980, when high-yielding, fertilizer-responsive varieties of rice were widely adopted and the government introduced subsidies for fertilizers and pesticides. The level of fertilizer subsidy was as much as 50% from the mid-1970s to the mid-1980s but then gradually declined and ended in 1999 (although subsequently it was reintroduced but at a relatively modest level). Average fertilizer application reached 105 kg/ha of harvested area by 2005 but was still low by international or even Asian standards (Mundlak, Butzer, and Larson 2004). Adoption of farm machinery accelerated after 1970, first for mechanical rice millers that replaced hand pounding and more recently for two-wheel walking tractors that are beginning to replace draft animals in tillage operations. However, the ratio of tractor horsepower to workers remained very low compared with other Asian countries like China and India. By 2002, there was only about 1 tractor in use per 250 farm households.

3. YIELD TRENDS

In this section, I examine yield trends of agricultural land and labor. I first describe resource productivity trends for the sector as a whole and compare land and labor productivity trajectories between densely populated Java and other land-abundant regions of the country. I then show yield trends for specific agricultural commodities over the 1961-2007 period, starting with food and horticultural crops. Nearly all of these crops are produced by farm families, most possessing less than two hectares of land. Next, I examine yield trends in estate crops and compare productivity levels between large plantations and smallholder estates. There is a wide range in the scale of estate holdings in Indonesia, from smallholders operating 1-2 hectares to large corporate and state farms that may operate over 100,000 hectares. The relation between scale and productivity in estate crop production has received considerable policy attention in Indonesia, as smallholder tree-crop producers are thought to have generally lagged behind large estates in technology, management, and yield (Barlow and Tomich 1991; Hartemink 2005). I compare yield and yield trends between smallholders and large estates for those commodities for which both have significant shares in production. Finally, I examine some productivity indicators for animal and cultured fish production, namely, meat and milk produced per head of stock and fish per hectare of area in ponds.

3.1. Agricultural Land and Labor Productivity

Hayami and Ruttan (1985) hypothesized that countries with different resource endowments would follow different paths of technological development in agriculture. Population-dense (land-scarce) Asian countries, they argued, would develop and adopt land-saving technologies like high-yielding crop varieties and fertilizers. Indonesia represents something of a special case, possessing both densely populated agricultural areas, mainly in Java, and large but sparsely populated regions in other islands. Figure 12.2 plots the trends in land and labor productivity (averaged over five-year intervals) for each decade from 1961-65 through 2001-05. Plotted along the vertical axis is average output per hectare of cropland while the horizontal axis shows output per worker. The plots show the productivity trajectories for Java and non-Java regions of the country as well as the average for the country as a whole. In Java, land and labor productivity both grew substantially between the 1960s and 2001-05, as farmers intensified production, first through green revolution rice technologies and later by shifting more resources into higher-valued horticultural, livestock, and aquaculture commodities. Land per worker fell over time as the agricultural population grew while agricultural land fell. On other islands (Sumatra, Kalimantan, and Sulawesi, primarily), expansion of land area was the primary source of growth, and land productivity hardly improved. Labor productivity increased, however, as the average cropland per worker rose. While the average productivity of farmland has been much higher on Java, the increasing area

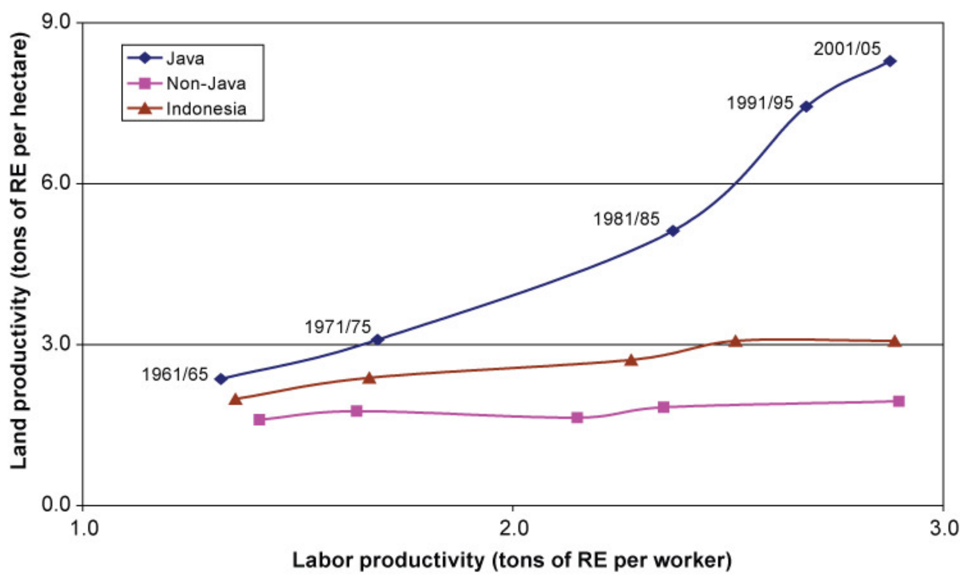

Figure 12.2. Land and labor production in Java and non-Java regions of Indonesia

Source: Author's estimates using data from BPS *Statistical Yearbook of Indonesia*, MOA and Van der Eng (1996).
Notes: RE = rice-equivalent value of total crop and livestock production. The points are the average annual values over the indicated five-year period.

worked per farm on non-Java islands served to close the gap in labor productivity between these regions.

3.2. Food Crops

Yield trends for rice and other food and horticultural crops are given in Table 12.5. Rice, which alone accounts for about half of the gross value of agricultural output, benefited considerably from dissemination of high-yielding green revolution varieties in the 1970s and 1980s. There are about 8 million ha of wetland paddy area (4.5 million ha of which are irrigated) and 1 million ha of upland (unterraced) rice area in Indonesia. Much of the irrigated area is double-cropped, and total rice area harvested reached 11 million ha by 2005. Between the 1960s and 1980s, average yield per hectare of harvested area doubled from 1.9 tons/ha to 4.0 tons/ha. But yield growth slowed markedly in the 1990s, and rising to only 4.5 tons/ha by 2001-07. Growth in yield accounted for more than two-thirds of the total growth in rice production over most of the 1961-2007 period, with growth in area harvested accounting for the other third. Presently, the government of Indonesia is cooperating with a number of private breeding companies to develop hybrid rice varieties in an effort to raise yield.

Corn and cassava are the second most important food crops in Indonesia and are staple foods in certain regions of the country. They are also important co-staples with rice for poor households as well as used for animal feed and starch production. These crops (and other secondary food crops) are mostly grown on rain-fed cropland. Corn yield started to increase in the 1970s and has experienced steady growth, doubling from 1.2 tons/ha in 1971-80 to 3.3 tons/ha in 2001-07 as improved hybrid varieties became widely adopted (Table 12.5). Cassava yield has also grown, although yield growth has been uneven over time. Some improved varieties have been developed but adoption rates remain low, restricted mainly to Lampung Province in Sumatra where cassava is used by agro-processors to produce commercial starch and animal feed. Area planted to cassava has trended downward, so that production has grown at a slower rate than yield.

There has been virtually no yield growth in soybeans and mungbeans since the 1960s, with yield of both crops averaging around 1 ton/ha. Groundnuts, on the other hand, have seen some modest yield growth of about 1% per year, to rise from 1.2 tons/ha in the 1960s to 2.0 tons/ha in 2001-07. These crops are often grown in rain-fed paddy fields during the dry season following the rice harvest or in upland fields.

Table 12.5. Yield trends for rice, secondary food crops, and horticultural crops

Commodity	1961-70	1971-80	1981-90	1991-00	2001-07
Rice			(average over period)		
Average yield (mt/ha)	1.9	2.7	4.0	4.3	4.5
Annual yield growth (%/year)	3.3	3.3	2.7	0.2	0.9
Share of production growth due to yield	64	76	63	16	67
Corn					
Average yield (mt/ha)	1.0	1.2	1.8	2.4	3.3
Annual yield growth (%/year)	0.4	4.2	3.8	2.6	3.7
Share of production growth due to yield	17	121	73	72	106
Cassava					
Average yield (mt/ha)	7.5	8.7	11.0	12.1	15.0
Annual yield growth (%/year)	-0.1	2.6	2.2	0.4	3.7
Share of production growth due to yield	--	96	152	231	131
Soybeans					
Average yield (mt/ha)	0.7	0.8	1.0	1.2	1.3
Annual yield growth (%/year)	0.5	2.2	2.2	1.0	0.7
Share of production growth due to yield	32	81	27	--	--
Groundnuts					
Average yield (mt/ha)	1.2	1.4	1.7	1.8	2.0
Annual yield growth (%/year)	0.8	2.9	0.6	0.7	1.5
Share of production growth due to yield	63	51	19	60	81
Mungbeans					
Average yield (mt/ha)	1.1	1.0	1.3	1.2	1.0
Annual yield growth (%/year)	0.7	-3.2	4.8	-4.8	2.7
Share of production growth due to yield	--	--	76	--	191
Vegetables					
Average yield (mt/ha)	3.8	4.3	4.7	7.6	8.9
Annual yield growth (%/year)	0.6	1.0	3.9	2.6	1.3
Share of production growth due to yield	16	--	62	61	49

Table 12.5. Continued

Commodity	1961-70	1971-80	1981-90	1991-00	2001-07
Fruit crops			(average over period)		
Average yield (mt/ha)	1.7	1.8	1.9	2.4	3.6
Annual yield growth (%/year)	3.4	-1.1	1.1	1.9	7.1
Share of production growth due to yield	69	--	32	59	79

Source: FAOSTAT.

Note: Mungbeans are classified as "Beans, dry" in FAOSTAT.

Vegetable and fruit production has grown rapidly in Indonesia, especially since the 1980s. Growth in per capita income has increased the demand for high-valued fruits and vegetables. Principal vegetable crops include chilies, shallots, potatoes, and cabbages. Temperate zone vegetables like potatoes and cabbages are grown in cool tropical highlands. Yield improved following adoption of improved varieties, better-quality seed, fertilizers, and pesticides. Principal fruit crops include bananas, mangoes, oranges, and papayas. Typically, farmers grow many varieties of these fruits for home consumption and market sales. Average yield of fruits has improved somewhat as farmers have increased commercial fruit production.

3.3. Estate Crops

Estate crops have played an important role in the Indonesia archipelago since the sixteenth century, when the country was the sole source of global supply of exotic spices like nutmeg, cloves, and pepper. In the nineteenth century, Indonesia emerged as a leading exporter of sugar and coffee. In the early twentieth century, colonial and smallholder estates responded to the raw material demands of the emerging global auto industry by greatly expanding area in rubber production, and by the 1920s rubber had become the dominant export crop of Indonesia (Kano 2008). Export-oriented estate production suffered a major reversal when commodity prices collapsed during the Great Depression. Production was further disrupted by World War II and the War of Independence (1945-49), although it began a modest recovery in the 1950s until foreign estates were nationalized in 1957. In the 1970s the government of Indonesia initiated major programs to expand estate crop production, especially in sparsely populated regions of Sumatra, Kalimantan, Sulawesi and Papua. A "transmigration" program resettled farm families from densely populated Java, and elsewhere to these regions. A "nucleus-estate" program provided corporations with subsidized capital and long-term leases to public lands for estate crop production, on condition that these companies provide technical and marketing services to smallholder estates surrounding the company plantations. Nucleus estate schemes were especially important for the oil palm industry, which greatly expanded after 1980. By 1999, oil palm became the dominant estate crop, surpassing both rubber and coconut in total area planted. The government of Indonesia estimates that more than 7.2 million ha were planted to oil palm in 2009, accounting for about one-third of the total area in estate crops. Cocoa also has also undergone a major expansion since the 1980s, with area planted rising from less than 40,000 ha in 1980 to an estimated 1.47 million ha in 2009.

While smallholders dominate production of a number of estate crops, both smallholders and large private and state-owned companies participate in the production of oil palm, rubber, cocoa, sugarcane, and tea. Table 12.6 shows the percentages of total area planted by smallholders for these commodities and compares the average yields obtained on smallholder farms and large estates over time. Smallholders have dominated rubber production (with over 80% of total area) since before the 1960s and account for nearly all of the growth in cocoa area since 1980. Large estates (mostly privately owned) account for most of the area in oil palm, but the role of smallholder producers has steadily risen. By 2001-07, smallholders accounted for 40% of the total area planted to oil palm in Indonesia. State-owned estates play a major role in tea and sugarcane production, and shares of smallholders in these crops have fluctuated over time but show no pronounced trend.

While family-owned or managed farms are the dominant (and most efficient) form of farm structure, Binswanger and McIntire (1987) identify conditions under which large corporate estates may achieve economies in agricultural production. Large estates can usually access lower-cost capital and thus will have some cost advantages over smallholders (at least initially) in crops for which a significant capital investment with a long payoff period is required, such as with tree crops. Large estates may also have advantages with certain crops that require close coordination between harvesting and processing due to rapid perishability of the harvest. Crops that fit this category include oil palm fruit, sugarcane, and tea leaves. However, large estates also have disadvantages, particularly in the management and oversight of labor. Hired labor is likely to have weaker incentives than family labor to perform myriad farm tasks in a timely and efficient manner.

Table 12.6 indicates that while smallholders initially had smaller yields than large estates, the yield gaps have diminished over time. By 2001-07, average smallholder yields in oil palm, sugarcane, and cocoa approached or exceeded average yields on large estates. Only in rubber and tea production did large estates obtain consistently better yields than smallholders. However, the lower average yield of smallholder rubber growers partly reflects lower tree density on these farms rather than yield per tree. Unlike large estates, which emphasize monocropping, smallholder estates typically use a mixed cropping system in which rubber trees are planted with lower density to accommodate other species of crops on the same land (Tomich et al. 2001).

Table 12.6. Area and yield of large and small estate crop producers

Commodity	1971-80	1981-90	1991-00	2001-07
		(average over period)		
Oil palm				
Total area planted (thousand ha)	206	646	2,501	5,472
Share of area planted by smallholder estates	0	16	30	40
Yield of smallholder estates (kg/ha planted)	184	522	1,455	1,868
Yield of large estates (kg/ha planted)	2,053	2,531	2,220	2,171
Rubber				
Total area planted (thousand ha)	2,336	2,785	3,440	3,310
Share of area planted by smallholder estates	80	83	85	85
Yield of smallholder estates (tons/ha planted)	322	324	391	574
Yield of large estates (tons/ha planted)	561	702	717	825
Cocoa				
Total area planted (thousand ha)	22	152	585	1,049
Share of area planted by smallholder estates	33	55	74	90
Yield of smallholder estates (tons/ha planted)	135	222	563	664
Yield of large estates (tons/ha planted)	239	467	453	606
Sugarcane				
Total area planted (thousand ha)	215	352	397	361
Share of area planted by smallholder estates	48	74	60	54
Yield of smallholder estates (tons/ha planted)	3,482	5,659	5,294	5,280
Yield of large estates (tons/ha planted)	8,235	4,629	4,706	5,764
Tea				
Total area planted (thousand ha)	102	120	146	143
Share of area planted by smallholder estates	35	41	41	44
Yield of smallholder estates (tons/ha planted)	430	516	553	649
Yield of large estates (tons/ha planted)	935	1,410	1,441	1,580

Table 12.6. Continued

Commodity	1971-80	1981-90	1991-00	2001-07
Estate crops with over 95% of area planted by smallholders		(average over period)		
Coconut				
Total area planted (thousand ha)	2,271	3,085	3,669	3,849
Average yield (kg copra/ha)	641	628	741	818
Coffee				
Total area planted (thousand ha)	353	623	868	1,302
Average yield (kg/ha)	567	560	541	497
Clove				
Total area planted (thousand ha)	243	640	509	442
Average yield (kg/ha)	102	80	136	177
Tobacco				
Total area planted (thousand ha)	177	208	202	228
Average yield (kg/ha)	506	561	712	800
Pepper				
Total area planted (thousand ha)	55	93	130	196
Average yield (kg/ha)	603	548	459	421

Source: MOA.

3.4. Livestock and Fisheries

Table 12.7 shows production and yield trends for meat, milk, and aquaculture in Indonesia. Rising per capita income has increased demand for these products domestically while shrimp is an important export item. Meat production doubled between the 1970s and 1980s, and more than doubled again by 2001-06 to more than 2.2 million tons per year. The total stock of animals, measured in "cattle equivalents" averaged 34 million head in 2001-06.[1] The fastest-growing component of meat production has been for poultry. Advances in production efficiency, particularly in commercial broiler production, have steadily increased annual meat production per head of cattle-equivalent animal from 40 kg/head in the 1970s to 66 kg/head in 2001-06.

Dairy is a relatively small industry in Indonesia but has grown over time, especially between the 1970s and 1990s. Improved breeds, feed, and veterinary care has helped raise milk output per cow. During 2001-06, each cow produced on average 1,471 liters of milk per year, more than double the average milk yield in the 1970s.

Table 12.7. Production and yield trends in meat, milk, and fish production

Commodity	1971-80	1981-90	1991-00	2001-06
Meat	(annual average over period)			
Production (thousand tons)	551	1,068	1,803	2,233
Animal stock (million cattle equivalents)	14	22	31	34
Yield (kg per head of stock)	40	50	58	66
Milk				
Production (million liters)	53	209	403	536
Milking cows (thousand head)	85	216	331	364
Yield (liters per cow)	627	967	1,215	1,471
Cultured fisheries (brackish & freshwater)				
Production (thousand tons)	161	344	648	1,062
Area in ponds, cages, and paddy fields (thousand ha)	267	370	548	736
Yield (kg per hectare)	602	930	1,181	1,442
Capture fisheries (marine & inland)				
Production (thousand tons)	1,489	2,502	4,210	5,645

Sources: Meat and milk statistics from FAOSTAT. Fisheries statistics from BPS *Statistical Yearbook of Indonesia*.

[1] "Cattle equivalents" are estimated by weighting various species of livestock and poultry by their size relative to cattle. Weights are from Hayami and Ruttan (1985) and are as follows: cattle = 1.00, buffalo and horses = 1.25, pigs = 0.25, small ruminants = 0.13, and poultry = 0.0125.

Fish production is an important industry in the Indonesian archipelago. Although marine and inland capture fisheries account for most fish production, output from capture fisheries has stagnated and growth in fish production now comes almost entirely from cultured fisheries. By 2001-06, farmers had developed over 700,000 hectares of ponds, which produced more than 1 million tons of fish and shrimp, or about 16% of total fisheries output in Indonesia (BPS, *Statistical Yearbook of Indonesia*). Output per hectare of land in ponds also rose over time, because of adoption of technologies that allowed shrimp and other species to be farmed in higher densities. Since 2001, white shrimp (*Penaeus vannamei*) have largely replaced black tiger prawns (*P. monoden*) in Indonesia and other Asian fisheries as a result of advances in white shrimp pathogen-free propagation and breeding methods (Shaun Moss, Oceanic Institute, Hawaii Pacific University, personal communication 2008).

4. TOTAL FACTOR PRODUCTIVITY OF INDONESIAN AGRICULTURE

In a multi-output, multi-input enterprise like agriculture, land and labor productivity trends like those described in the previous section give an imperfect measure of technical change, since they are also influenced by how intensively other inputs are used in production. In this section, I develop a measure of total factor productivity for the agricultural sector as a whole. Changes in TFP reflect an improvement in efficiency with which all inputs are employed and provide a more robust measure of technical change in the sector.

4.1. Methodology

For assessing changes in TFP, I construct Tornqvist-Thiel indexes of aggregate output and input quantities, and then take the ratio of these as an index of TFP. In other words, TFP measures the average product of all inputs. Let the total quantity of outputs be given by Y and the total quantity inputs by X. Then TFP is simply

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

Changes in TFP are found by comparing the rate of change in total output with the rate of change in total input. Expressed as logarithms, changes in equation (1) over time can be written as

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

Since X and Y are composed of multiple inputs and outputs, an aggregation procedure is needed to construct the index. Solow (1957) showed that under the assumptions that (i) producers maximize profits and (ii) markets are in long-run competitive equilibrium, then equation (2) can be written as

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

where R_i is the revenue share of the ith output and S_j is the cost-share of the jth input. Output growth is estimated by summing over the output growth rates for each commodity after multiplying each by its revenue share. Similarly, input growth is found by summing the growth rate of each input, weighting each by its cost share. TFP growth is just the difference between the growth in aggregate output and aggregate input. A discrete time approximation of the Divisia index given in equation (3) is the Tornqvist-Thiel productivity index:

$$\ln\left(\frac{TFP_t}{TFP_{t-1}}\right) = \sum_i \frac{\left(R_{i,t} + R_{i,t-1}\right)}{2} \ln\left(\frac{Y_{i,t}}{Y_{i,t-1}}\right) - \sum_j \frac{\left(S_{j,t} + S_{j,t-1}\right)}{2} \ln\left(\frac{X_{j,t}}{X_{j,t-1}}\right). \tag{4}$$

Denny and Fuss (1983) showed that the Tornqvist-Thiel TFP index in equation (4) can be derived from a translog production function that exhibits Hicks-neutral technical change. Because the translog is a flexible function form, the Tornqvist-Thiel index provides a superior measure of productivity change than alternatives that assume a more restrictive production relationship.

A further modification of the index construction is to account for changes in labor quality over time. I construct a labor quality index based on the average schooling level achievement of the male and female agricultural labor force. Specifically, let $L_t^* = \lambda_t L_t$, where L_t^* is the observed number of work days in year t, λ_t is a quality indictor of educational achievement, and L_t is the labor force measured in constant-quality units. Using a Mincerian-type earnings function, the labor force quality indicator is specified as

$$\lambda_t = \exp\left(\alpha\, s_t\right) \tag{5}$$

where s_t is the average educational level of the farm labor force and α is the percent increase in labor productivity due to education (i.e., $d\ln(\lambda_t)/ds_t = \alpha$). This allows us to decompose the effects of changes in labor quantity and quality on agricultural growth over time. The Mincerian interpretation of equation (5) is that *s* is the average number of years of schooling and α is the rate of return to an additional year of schooling (Psacharopoulos and Patrinos 2004).

4.2. Data

Recent improvements in the quality and coverage of data on agricultural production and input use have facilitated measurement of agricultural productivity change in Indonesia. Van der Eng (1996) developed long-term series (1880-1992) for outputs and prices of major crop and livestock commodities as well as land and labor inputs. For the post-1960 years, Van der Eng's (1996) data, which are based on Indonesian government sources, provide superior estimates of cropland for Indonesia than FAO estimates (which substantially underestimate historical land-use changes for this country). I recently (Fuglie 2010) further improved on these series by developing a more complete measure of area in perennial crops since 1961.

For agricultural output, I use FAO data to measure annual gross production of 55 crop commodities and 19 livestock commodities since 1961.[2] I also include output from cultured fisheries (which include brackish and freshwater ponds, cages, and paddy fields) using estimates from the *Statistical Yearbook of Indonesia* (BPS). Production figures are given in total metric tons and do not distinguish by species. However, FAO's FIGIS dataset[3] breaks down cultured fisheries production by species (diadromas, pelagic, demersal, crustacean, mollusks, cephalopods, other marine fishes, and other freshwater fishes), which I use to estimate the value of production together with species-specific price data.

For commodity prices, the ideal measure would be the average price received by farmers, but the only data series with sufficient coverage available for Indonesia are wholesale prices. The FAO "producer price" series (available for most crop and livestock commodities since the mid-1960s) and Van der Eng's (1996) "rural

[2]I follow the Indonesian classification system for crop commodities whereby food crops (*palawija*) include rice, corn (maize), cassava, soybean, mungbean, and sweet potato; horticultural or garden crops include other vegetables and fruits; and estate crops include oil palm, rubber, coconut, sugar, coffee, cocoa, tea, tobacco, fiber crops, nuts, spices and other specialty crops.

[3]FIGIS and BPS's *Statistical Yearbook of Indonesia* define marine and freshwater fisheries differently but report nearly identical aggregate estimates of fish production for Indonesia (FIGIS includes harvest of aquatic animals, plants, and corals in aggregate fisheries production while the BPS yearbook excludes these species). In terms of resource use, BPS assigns all production from aquaculture (brackish or freshwater) to cultured fisheries while FIGIS allocates production to either marine fisheries (including brackish pond aquaculture) or inland fisheries (including cultured production and open water catches).

bazaar prices" for selected crops closely track the Jakarta wholesale commodity prices published by BPS (*Statistical Yearbook*). For this study I used *Statistical Yearbook* annual price series for 14 commodities (major food and estate crops, beef, and eggs) and FAO producer prices for horticultural crops and minor estate crops. Supplemental price data for some estate crops (cane sugar, kapok fiber, and ginger) are from the Indonesia Ministry of Agriculture (MOA). Van der Eng (1996) price data were used to fill in for gaps in the series, especially for the early 1960s. Fish prices for the eight categories of fish outputs are export prices derived from FAO trade data. For some commodities, consistent price series were established in Indonesia only in the late 1960s or early 1970s. For missing years, the average normalized price (commodity price relative to the price of rice) for the nearest five-year period for which price data were available were used to extend the series back to 1961. The normalized (relative) prices were then used to construct revenue shares for those years.

To account for marketing margins between prices received by farmers at harvest and at wholesale, I assume an average marketing margin for all commodities of 20%. Mears (1981), in a comprehensive study of rice marketing in Indonesia, estimated marketing costs between farm and wholesale levels in the late 1970s to be between 15% and 25% of the farmgate price of rice. While only one commodity, rice does account for about half of agricultural output in Indonesia. For the purposes of forming the agricultural output index, this assumption about the marketing margin is innocuous since it does not affect the relative prices among commodities, which are used to aggregate outputs. However, it does affect the cost share attributed to land, which is estimated as a residual after other costs are deducted from total revenue.

The land input measure includes five classes of agricultural land: irrigated cropland, other (rain-fed) terraced rice lands, area in garden and upland crops, area planted to perennial crops (including immature trees), and area in cultured fisheries. These data are from the *Statistical Yearbook of Indonesia* (supplemented with data from Van der Eng 1996 for some years), except for area planted to perennials, which is from MOA. The MOA data provide a more complete coverage of total area planted to perennial crops, including immature and other non-producing trees. The annual growth rate in total agricultural land is derived from a quality-adjusted aggregation of the different land classes. I assign quality weights to each type of land based on the average gross value of output per hectare of resource. Letting the quality weight for uplands be 1.00, the weights for the other land classes are as follows: 4.0 for irrigated wetland rice, 2.0 for non-irrigated wetland rice, 1.5 for cropland planted to perennials, 2.0 for freshwater ponds, 1.0 for brackish water ponds, and 0.5 for paddy fisheries. One way to interpret these weights is that they reflect (relative) returns to investments in land improvement. Agricultural land with more improvements in the form of irrigation, terracing, tree planting, and pond structures are more productive than land without these features and have a higher quality weight. The weight on paddy fisheries reflects the augmentation in resource value when fish are produced jointly with paddy rice.

For agricultural labor, I use FAO estimates of the number of economically active male and female adults in agriculture. Wages for male and female workers are average daily wages paid for crop weeding (BPS, *Farm Cost Structure of Paddy and Secondary Food Crops*). To find total annual labor costs, daily wages are multiplied by 300 days worked per year for men and 250 days worked per year for women. I adjust for improvements to labor quality by considering the average years of schooling of the agricultural labor force. To derive the effect of schooling on labor quality, I assume the increase in productivity from an additional year of schooling to be 7% for men and 8% for women, using Kawuryan's (1997, p. 218) estimate of the marginal private rate of return to primary schooling. Kano (2008) reports the share of the agricultural labor force with various schooling levels in 1971, 1980, 1990, and 2000, based on population censuses and SAKERNAS surveys. I estimated the average years of schooling for a worker in the agricultural labor force from these data by multiplying 0, 3, 6, 9, 12, and 15 years of schooling times the share of farm workers with no schooling, incomplete primary, completed primary, incomplete secondary, completed secondary, and post-secondary schooling, respectively, and interpolate for intervening census years.

Annual applications of chemical fertilizers (N, P_2O_5, and K_2O) are from FAO. Prices paid by farmers for fertilizers are from BPS *Agricultural Indicators*. Published data on pesticide inputs in agriculture are fragmentary. FAO reports tons of active ingredients of fungicides, herbicides, insecticides, and other chemicals consumed for 1990-1993 only. But these figures are substantially lower than those reported for 1980-1996 by Oudejans (1999), who obtained data from the agro-chemical industry. Based on Oudejans's figures and my estimate of aggregate agricultural revenue, it appears that pesticide costs did not exceed an 0.5% factor share in any year up through 1996. Because of the incompleteness of pesticides data, the data are not included in the input aggregation.

Mechanization in Indonesian agriculture remains relatively low compared with other Southeast Asian countries, and information on farm machinery capital inputs and their related costs is quite limited. In the 1970s there was widespread adoption of mechanical rice millers that replaced hand-pounding, which generated considerable controversy over rural labor displacement (Timmer 1998). In the 1990s the number of two-wheel walker tractors and water pumps grew rapidly from low initial levels. By 2001-05, only about 100,000 tractors (nearly all two-wheel) were in use among nearly 25 million farms, or about 1 tractor per 250 farm households. To measure agricultural machinery input, I estimate total tractor horsepower in use using the number of tractors by size (BPS, *Statistical Yearbook*) times the average horsepower per tractor for each size class. The annual cost of capital services is determined by estimating an annual service flow per horsepower and multiplying this by the total stock of horsepower of farm tractors. To estimate the annual service flow per horsepower, I use FAO data for the average import price for tractors and then amortize this price assuming a 10-year life span and a 10% discount rate. I then divide this cost by the average horsepower/tractor in service for each year to derive the annual depreciation cost of 1 horsepower of capital services. I then double this to account for other farm implement costs as well as fuel and repair costs.

Animal capital is measured as the annual stocks of buffalo, beef cattle, dairy cows, horses, pigs, small ruminants, and poultry (FAOSTAT). The relevant price weight for an animal input is the value of services from that animal in a given year. Prices for live animals are FAO import values for cattle, buffalo, horses, and sheep and export values for pigs and poultry. To derive annual service flows for long-lived species (large ruminants), the purchase prices are amortized over three years using a 10% discount rate.

Seed and feed inputs are from the FAO commodity balance sheets supplemented with feed data from the USDA's Production, Supply and Distribution database (PSD Online). The USDA data, which primarily cover raw materials used by commercial feed manufacturers, are used to measure feed from domestic and imported corn, by-products from wheat milling, and meal by-products from soybeans, oil palm, and copra and fish processing. FAO data are used for other sources of feed and include by-products from rice milling (bran and broken rice), molasses from sugar processing, tuber crops, meat meal, and milk fed to young animals. Feed prices are domestic commodity prices for rice, corn, and milk; FAO export values for rice bran, dried cassava, copra meal, oil palm meal, and molasses; and FAO import values for soymeal and fishmeal. Seed prices are set at 1.5 times the corresponding domestic commodity prices.

4.3. Results: Tornqvist-Thiel Indexes of Agricultural Output, Input, and TFP

Tornqvist-Thiel annual index series for aggregate agricultural output, input, and TFP are given in Table 12.8. The contribution of TFP to agricultural growth was relatively high during the 1960s and 1970s when green revolution crop varieties were widely adopted. During the 1980s, TFP growth slowed but resource expansion accelerated to sustain overall growth of the sector. The low growth during the 1990s partly reflects stagnation in productivity and the impact of the Asian financial crisis in 1997-98 when a sharp devaluation of the Indonesian currency caused the livestock sector, which was heavily dependent on imported feed, to sharply contract. In recent years (2001-2006), TFP growth rose to levels as high as or higher than the peak years of the green revolution. A number of factors may have contributed to the return to high TFP growth: adoption of improved technology, diversification into high-valued commodities, and land expansion into tree crops. The latter two factors affect TFP through resource-use efficiency rather than through technical change. By shifting the allocation of farm resources from production of lower-valued to higher-valued products, more real output is obtained per unit of input. Tree crop production can employ farm labor more fully over an entire year, especially when done in conjunction with food crop production on a farm, and thus increase hours worked per farm worker. Since labor is measured as the number of economically active workers, an increase in output due to a rise in average hours worked per capita appears in the estimation as an increase in TFP.

4.4. Policies and Productivity in Indonesia's Agricultural Development

In this section, I divide 1961-2006 into four periods, each reflecting a different policy orientation toward agriculture, and compare the growth performance of the sector during each period. The first period, 1961-1967, marks the final years of the Sukarno Guided Democracy era during which Indonesia suffered from macroeconomic and political instability. The second period, 1968-1992, reflects the early policies of Suharto's New Order regime when agriculture and food security were given precedence in economic policy. These policies included large state subsidies for agricultural inputs, intervention in markets for food staples, and the promotion of green revolution crop varieties. However, by the mid-

Table 12.8. Output, input, and total factor productivity (TFP) indexes for Indonesian agriculture

	Crops, Animals, and Aquaculture		
Year	Output	Input	TFP
1961	100	100	100
1962	106	102	105
1963	101	102	99
1964	106	102	104
1965	108	105	102
1966	112	105	106
1967	108	104	103
1968	126	112	112
1969	130	108	120
1970	139	109	128
1971	143	111	128
1972	144	113	128
1973	156	113	137
1974	161	115	140
1975	161	116	139
1976	161	117	138
1977	169	120	140
1978	178	124	144
1979	186	127	146
1980	203	129	157
1981	218	135	161
1982	217	139	157
1983	234	147	159
1984	253	154	165
1985	262	156	168
1986	281	162	173
1987	285	170	168
1988	299	173	173
1989	313	178	176
1990	326	184	177
1991	332	188	177
1992	359	193	186
1993	362	197	184
1994	364	204	179
1995	397	209	190
1996	401	213	188
1997	386	212	182
1998	383	205	186
1999	392	205	192
2000	404	207	196
2001	412	210	196
2002	435	216	202
2003	464	219	212
2004	486	219	222

Table 12.8. Continued

	Crops, Animals, and Aquaculture		
Year	Output	Input	TFP
2005	495	224	221
2006	510	225	226
Average annual growth rates (%)			
1961-1970	3.66	0.96	2.70
1971-1980	3.78	1.67	2.10
1981-1990	4.74	3.54	1.20
1991-2000	2.16	1.18	0.98
2001-2006	3.86	1.43	2.43
1961-2006	3.62	1.80	1.82

Source: Author's estimates.

1980s trade and fiscal imbalances led to a gradual shift in economic policies in favor of export-led manufacturing. Moreover, public subsidies and investments in agriculture began to wane (Fuglie and Piggott 2006). Diffusion of modern rice varieties and irrigated area as a share of total cropland both plateaued in the early 1990s (at about 80% of rice area and 14% of total cropland, respectively). Although there is no single date in which Indonesia's agriculture-first policy ended, I choose 1993 as the beginning date for what I call the "stagnation" period for Indonesian agriculture. Following the severe economic contraction and political crisis caused by the Asian financial crisis of 1997-1998, the country emerged with a new "reform" government and a more market-oriented agricultural policy. A sharp devaluation of the currency, liberalization of food crop markets, and changes in land-use policy shifted comparative advantage in agriculture toward export commodities like tropical perennials. The fourth period, 2002 to the present, I call a "liberalization" period in which market forces played a larger role in allocating resources to and within the agricultural sector.

The sources of agricultural growth during each of the four periods are shown in Table 12.9. For each period I decompose growth into the share explained by resource expansion and the share due to productivity improvement. I further decompose growth in labor productivity (output per worker) into changes in land per worker, capital per worker, education, and TFP.

During the first period of political and macroeconomic instability (1961-1967), agricultural output grew by only 1.24% per year, less than the rate of population growth. There were very few modern inputs employed in production and very little improvement in TFP. The estate crop sector was still depressed

Table 12.9. Sources of growth during episodes of Indonesia's agricultural development

Growth Measures	Stages: Instability 1961-1967	Stages: Green Revolution 1968-1992	Stages: Stagnation 1993-2001	Stages: Liberalization 2002-2006	Whole Period 1961-2006
	Average annual growth rate (%)				
Total output	1.24	4.82	1.51	4.31	3.62
Total inputs	0.71	2.47	0.93	1.36	1.80
Total factor productivity (TFP)	0.54	2.35	0.58	2.95	1.82
Workers[a]	0.02	0.29	0.01	-0.28	0.13
Output/worker[a]	1.23	4.53	1.51	4.59	3.49
Land/worker[a]	0.15	0.21	0.24	0.61	0.26
Other inputs/worker[a]	0.35	1.62	0.37	0.62	1.09
Education	0.19	0.35	0.31	0.41	0.33
TFP	0.54	2.35	0.58	2.95	1.82

Source: Author's estimates.

[a]The number of agricultural workers is measured in constant-quality units after adjusting for changes in the average schooling level of the agricultural labor force. Land includes land in crops and ponds, quality-weighted by type of land resource. "Other inputs" include all other measured inputs: animals, machinery, seed, feed, and fertilizer.

following the nationalization of foreign-owned estates in 1957 (Booth 1988), and efforts to boost productivity of food crops suffered from a lack of appropriate new technologies (Jatileksono 1987).

The growth performance of agriculture improved significantly during the green revolution period (1968-1992). The priority given by the New Order government to food crop production was greatly aided by the timely development of high-yielding rice varieties by the International Rice Research Institute in the Philippines. These varieties were well-adapted to irrigated agriculture in tropical Southeast Asia and responded well to higher levels of fertilizer (Darwanto 1993). Using revenues from oil exports, the government promoted the new varieties and heavily subsidized fertilizers and irrigation development (Jatileksono 1987). It also intervened in agricultural markets by restricting food imports and guaranteeing prices received by farmers (Timmer 2003). The New Order government also encouraged the expansion of cropland in sparsely populated regions of the country by subsidizing migration from Java and the planting of estate crops. A major program was the "nucleus estate" scheme in which plantation companies, in exchange for state-backed financing and long-term leases to public land, were obliged to provide processing and other services to smallholders in the areas surrounding the large estates (Potter and Lee 1998). During this green revolution stage (1968-1992), agricultural output growth accelerated to 4.8% per year. About half of this growth was due to resource expansion (including expansion of cropland, irrigated area, and fertilizer use) and about half to TFP growth. Growth in output per worker averaged 4.5% per year, which was driven by the increase in TFP as well as growth in material inputs (especially fertilizer) per worker. The growth in output per agricultural worker had a major impact on reducing rural poverty and food insecurity in the country (Timmer 2004).

By the early 1990s, modern crop varieties had been widely disseminated, but further sources of technological progress were not immediately forthcoming. The agricultural research system was apparently not sufficiently developed to deliver post–green revolution technologies that could sustain productivity growth (Fuglie and Piggott 2006). Further, the redirection of national priorities from agriculture to manufacturing reduced investments in the sector. Although food crops continued to receive trade protection and price supports, Indonesia became a large importer of cereal grains (wheat and feed grains, primarily). The livestock sector severely contracted during the Asian economic crisis when the currency was devalued and feed imports became prohibitively expensive (Simatupang et al. 1999). During the "stagnation" period (1993-2001), agricultural output growth averaged only 1.5% per year and TFP growth only 0.6% per year. Resource expansion slowed markedly, in part because of fewer resources for fertilizer subsidies and estate crop schemes, the end of government-sponsored migration, and the contraction in livestock capital during the 1997-98 Asian financial crisis.

By 1999 a new "reform" government was in power and the economy gradually recovered from the Asian financial crisis. One outcome of the crisis was liberalization of the agricultural sector: import restrictions on food crops were removed and fertilizer subsidies ended (Fuglie and Piggott 2006). Other policy changes, such as the 1999 Forestry Law and the 2001 Local Autonomy Law, affected control and access to public lands for agricultural development (Contreras-Hermosilla and Fay 2005). Between 2002 and 2006, agricultural growth resumed a rapid pace of over 4% per year and TFP growth accounted for about 60% of this growth. While the labor force remained almost constant, land per worker and other inputs per worker each grew by about 0.6% per year. The growth in cropland per worker occurred entirely outside of Java. Land expansion was particularly pronounced for tree crop plantings. By expanding area in estate crops, farmers could make fuller and more productive use of their labor during the agricultural season. Farmers who settled previously forested or degraded forest lands may have initially emphasized subsistence food crop production in "swidden" or shifting agricultural systems but gradually established mixed food-tree cropping systems involving oil palm, rubber cacao, coffee, and other perennials (Tomich et al. 2001; Belsky and Siebert 2003). The planting of tree crops was also a means of establishing tenure over these newly opened lands (Otsuka et al. 2001). On Java, meanwhile, agriculture also underwent intensification and diversification, with resources shifting from food and estate crops toward higher-valued horticulture, animal, and aquaculture production. However, the expansion of crops onto previously forested areas has raised environmental concerns. Soil erosion from cropland (Lindert 2000), biodiversity losses from forest conversion to oil palm monoculture (Koh and Wilcove 2008), and greenhouse gases emitted from peatland drainage (Couwenberg, Dommain, and Joosten 2009) have been found to be substantial, although these changes appear to primarily affect the supply of ecological services and not agricultural productivity.

Finally, Table 12.9 shows a steady but growing contribution of farmer education to productivity growth. Over the 1961-2006 period, the increase in average farmer education accounted for about 10% of the total growth in agricultural labor productivity. Moreover, the contribution of education to growth gradually increased over time. Since the early 1990s, the agricultural labor force has increased primarily in quality rather than quantity. It is likely that before the end of this decade agricultural employment in Indonesia will be in absolute decline. Raising the educational level of agricultural workers can offset this decline so that the transfer of labor from agriculture to other sectors will not be a drag on agricultural growth.

5. SUMMARY AND CONCLUSION

In the early years of the twenty-first century, agriculture in Indonesia reemerged as a dynamic sector of growth following a decade of post–green revolution stagnation. Once heavily dominated by rice production, the country's agriculture has become increasingly diversified, with perennials, horticultural crops, livestock, and aquaculture growing in relative importance over time. Indonesia has become a significant global supplier of tropical vegetable oil, rubber, cocoa, coffee, fish, and shrimp. Although the country continues to rely on imports for a significant share of its cereal grain needs for food and feed, it maintains a positive agricultural trade balance overall.

Resource expansion and productivity improvement have been important sources of growth in Indonesian agriculture. Agricultural land continues to expand in the sparsely populated regions of the country where area planted to perennial crops, oil palm especially, has undergone rapid expansion in recent decades. These regions include the islands of Sumatra, Kalimantan, Sulawesi, and Papua. Both smallholder farms and large estate companies are heavily involved in the perennial-crop sector. Large estate companies, with better access to capital and technology, often dominate the early stages of perennial crop development, but over time, smallholders catch up. Presently, smallholders dominate the production of rubber, coffee, cocoa, and coconut and are gaining market share in oil palm. Yield gaps between smallholders and large estates have also diminished over time. Nonetheless, cropland expansion into previously forested areas and peatlands has raised serious concerns about the loss of ecological services such as greenhouse gas sequestration and biodiversity preservation. The trade-off between agricultural and environmental outputs from these resources is an important issue needing further exploration.

Growth accounting provides a useful tool for assessing and decomposing sources of economic growth. Using the Tornqvist-Thiel index method, I find that Indonesia achieved an annual growth rate in agricultural production of 3.6% over the 1961-2006 period. Slightly more than half of this growth can be attributed to improvement in total factor productivity and the rest to resource expansion (increases in land, labor, capital, and intermediate inputs). Over the course of 1961-2006, agricultural labor productivity (in quality-adjusted units) increased at an average annual rate of 3.5%, and higher levels of schooling in the farm population accounted for about 10% of this growth. Continued improvement in the quality of labor can offset the expected decline in the size of the farm labor force in coming years.

Total factor productivity growth in agriculture accelerated during the green revolution period (1968-1992) when the government followed an agriculture-first development strategy and modern varieties of food crops were widely disseminated. However, TFP growth stagnated in the 1990s and did not resume until the country recovered from the Asian financial crisis and liberalized its policies toward agriculture. It appears that commodity diversification has been an important source of measured TFP growth in recent years. Farmers increased productivity by moving to more intensive production systems involving perennials, horticulture, animals, and aquaculture as well as food crops. This not only shifted resources to the production of higher-valued commodities but also made fuller use of farm labor. Moreover, the private sector rather than the state appears to be the driving force behind the reemergence of growth in this sector. Nonetheless, the gains from diversification were preceded by an impressive improvement in productivity of rice and other food staples. Having first secured food security may well have encouraged smallholder farmers to allocate more resources to producing non-staple commodities for the market.

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CHAPTER 13

South African Agricultural Production and Productivity Patterns

Frikkie Liebenberg and Philip G. Pardey

1. INTRODUCTION

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, notably a range of horticultural crops. Real agricultural output grew steadily, by 2.6% per year from 1910 to 1980, but growth slowed thereafter (to just 0.19% per year from 1980 to 2008). Here we document and discuss developments regarding aggregate input, output, and productivity developments within South Africa. To do so we draw on an entirely new set of production data stretching back to 1910/11 reported in Liebenberg 2010, as well as related evidence reported by other studies for South Africa and other countries within sub-Saharan Africa.[1]

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[1]Parts of this chapter also draw heavily on Liebenberg, Pardey, and Khan 2010.

2. AGRICULTURE IN THE SOUTH AFRICAN ECONOMY

After adjusting for inflation, South African agricultural gross domestic product (GDP) contracted by 1.1% per year from 1981 to 2006, compared with growth of 2.62% per year for GDP overall. Thus, agricultural GDP represents a declining share of the South African economy. Since 2005, its share has varied between 2.4% and 2.8%, compared with 12.3% in 1961, although the agricultural economy still employed more than 1.32 million farm workers, about 10.6% of the South African labor force, in 2006.

In 2006, South Africa's agricultural GDP was U.S.$6.9 billion, placing it 35th worldwide on this score (World Development Indicators Database). Agricultural trade constituted 2.7% of South Africa's GDP in 2006, with agricultural exports accounting for about 6.9% of total exports (DAS 2009). This is significantly less than its export share in 1932, when agriculture accounted for 78.4% of total South African exports. Since then, agricultural exports as a share of the country's total exports have declined steadily, to bottom out at 6.5% in 1993, after which the agricultural share grew to an average of 8.2% for the period 1994 to 2007. South Africa has always been a net exporter (by value) of agricultural products. In 1975, agricultural exports exceeded imports by R20.7 billion,[2] but the lingering effects of sanctions on imports from South Africa due to the apartheid regime combined with a failure to remain internationally competitive have left the country barely able to sustain its net agricultural exporter status in recent years.

In 1910, agricultural output (as indexed by AgGDP, a value-added measure of agricultural output) accounted for 19.3% of total economic output (GDP) (Table 13.1).[3] The agricultural share of total economic output declined steadily throughout the twentieth century, to just 2.5% by 2006. The absolute size of the agricultural economy grew almost every decade until the 1970s—at an overall average annual rate of 3.38% per year, from U.S.$2.4 billion (R9.3 billion) in 1910 to U.S.$11.8 billion (R45.9 billion) in 1974 (both measured in 2000 prices). From 1910 to 1928, real agricultural output grew by 1.8% per year. After the depression of the early 1930s and a severe drought for four years that ended in 1934, the agricultural economy experienced a period of strong growth in con-

[2]Here, and throughout this chapter, "R" denotes rand, the local currency unit of South Africa.

[3]AgGDP excludes output from the (processed) food sector. The combined output of the farm and agribusiness sectors (including food and fiber processors, distributors, and the relevant parts of the beverage industries like wine and beer—all of which are reported in the national accounts as part of the manufacturing sector) would almost double the sectoral share, such that the combined food and agricultural industries would constitute about one-third of total GDP.

Table 13.1. The changing structure of South African agriculture, 1910-2007

	Unit	1910s	1920s	1930s	1940s	1950s	1960s	1970s	1980s	1990s	2000 to 2007
Farming Structure						10-Year Average					
Farm number	Number	76,622	88,305	101,299	111,938	112,305	99,114	79,842	64,540	59,289	44,575
Total area	1000 ha	77,042	81,810	84,339	87,392	88,150	89,256	86,814	85,862	82,404	83,701
Average farm size	ha	1,006	928	833	781	788	817	1,094	667	1,260	1,400
Economic Contribution											
AgGDP	R million (2000)	9,207	10,596	10,379	18,223	33,136	35,508	37,594	35,877	30,201	31,217
Contribution to GDP	Percent	19.0	17.6	12.0	12.7	15.2	9.9	6.8	5.0	3.7	3.0
Labor											
Economically active in agriculture	'000	-	-	-	1,913	1,509	1,635	2,483	1,181	1,213	1,406
Agricultural share of total	Percent	-	-	-	42	33	29	31	14	10	12
Farm employees	'000	553	488	749	887	882	968	1,639	1,235	1,185	835
Value of Production											
Field crops	R million (2000)	4,063	4,568	5,339	8,938	14,982	20,267	26,524	23,658	15,677	16,722
Horticulture	R million (2000)	1,180	1,552	2,043	3,593	5,322	7,659	9,526	10,323	11,392	14,493
Livestock	R million (2000)	5,991	6,700	6,748	11,628	19,603	20,531	21,760	24,775	20,518	24,352
Total	R million (2000)	11,234	12,820	14,130	24,159	39,906	48,458	57,810	58,756	47,586	55,567

Table 13.1. Continued

	Unit	1910s	1920s	1930s	1940s	1950s	1960s	1970s	1980s	1990s	2000 to 2007
Share of Production Value											
Field crops	Percent	36	36	38	37	38	42	46	40	33	30
Horticulture	Percent	11	12	14	15	13	16	16	18	24	26
Livestock	Percent	53	52	48	48	49	42	38	42	43	44

Source: Liebenberg, Pardey, and Khan 2010.
Note: Data were deflated using the GDP deflator from SARB 2009.

junction with expanded farmer settlement and agricultural development support and reached U.S.$9.1 billion (R35.4 billion) in 1951, an increase of 8.95% per year for the 1934 to 1951 period. During the period 1951 to 1974, output growth slowed to an average of 2.27% per year. The agricultural economy then declined to a low point of U.S.$6.8 billion (R26.1 billion) in 1992, reflecting in part the effects of another severe drought in the 1991 and 1992 cropping seasons. Thereafter agricultural output rebounded to a peak of U.S.$9.6 billion (R37.1 billion) in 2002, after which international market pressures, changing domestic agricultural policies and economy-wide influences, and adverse weather conditions drove a period of decline.

The number of people economically engaged in agriculture grew virtually uninterrupted for 60 years from 1910 to the 1970s, when it reached 2.4 million. As reported, the number of farms increased over the same period from 76,149 to 90,422 in 1970 after peaking at 119,556 in 1952. With farm numbers continuing to decline thereafter, AgGDP per economically active person engaged in agriculture continued to grow in inflation-adjusted (2000 prices) terms, from U.S.$3,333 (R12,899) per capita in 1970 to U.S.$6,747 (R26,111) per capita in 2004.

3. AGRICULTURAL OUTPUT

The mix of agricultural output changed markedly over the years (Table 13.1 and Figure 13.1). In 1911 about 55% of the value of South African agricultural output was livestock products, with wool (20%), dairy (19%), and cattle and sheep (each contributing 15%) accounting for 68% by value of livestock production. By 2008 the livestock share had shrunk considerably, although still a substantial 44% of agricultural output by value (with poultry production now accounting for 55% of this total). The field crops share was 34% in 1911, grew to 47% in 1971 (largely because of an expansion of cereals and sugarcane production), declined significantly to 28% in 2004, and then regained some market share to reach 33% in 2008. A reduction in corn and wheat production accounted for most of the post-1971 decline. The share of horticultural output expanded steadily over the entire period since 1910, starting at 10% that year and increasing to 23% by 2008. Up until the late 1980s, the growth in the value of horticultural output averaged 3.9% per year—aided in part by improvements in cold chain management. After a brief downturn in output growth from 1989 to 1992, the sector resumed growing at impressive rates, especially

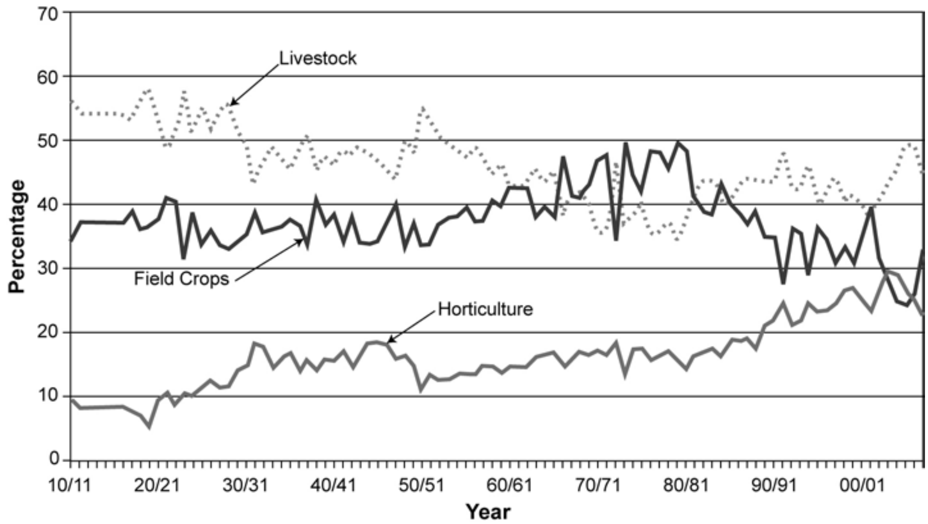

Figure 13.1. Sector shares in gross value of agricultural production, 1910-2008

Sources: Liebenberg 2010 based on data from DAS 2009.
Note: Livestock aggregate includes 11 commodities, field crops includes 22 commodities, and horticulture includes 12 commodities.

in the wine (4.41% per year from 1992 to 2004), deciduous fruit (5.01% per year) and citrus fruit (7.34% per year) sectors, partly in response to improved access to international markets as rest-of-world sanctions against imports from South African were scrapped.

These aggregate economic changes fail to reveal the different development paths followed by black versus white farmers. Throughout most of the post-unification period (specifically from 1913, but intensively so from the 1930s), the sustained and substantial government support to agriculture was biased toward white commercial farmers. Lacking a commensurate amount of public support, black farmers suffered as a consequence. The Land Act of 1913 and the Co-operatives Act of 1920 are two key examples of discriminatory public policy. The Land Act confined land ownership by blacks to dedicated native reserve, while the Co-operatives Act excluded black farmers from participating in farmer cooperatives. In 1925 the Farmer Assistance Board (the predecessor of the Agricultural Credit Board) was established to assist farmers with soft loans in the aftermath of the recession of the early 1920s. Black farmers were once again excluded from accessing these government-backed credit programs, and they were also excluded from participating in the farmer settlement programs introduced in the late

1930s.[4] Ostensibly, government support structures within the homelands and the self-governing territories were to take care of the needs of black farmers, but in fact these programs either failed to materialize or were never developed to the extent they were for the white commercial farming community.

The effect of these discriminatory policies over time is shown in Table 13.2 in which the current relative contribution of black farmers to national production and land ownership is tracked from 1918 to 2002. The share of farmed area owned by black farmers varied little from 1918 to 1991, averaging around 15%. This share then doubled to almost 31% of total farmed area by 2000, while the share of corn, wheat, sorghum, and pumpkin output produced by black farmers was substantially less in 2000 compared with earlier years. Likewise, the share

Table 13.2. Black farmers' share of area farmed and planted and national production of selected crops, 1918-2002

Year	Area of Farms	Planted	Corn	Wheat	Sorghum	Pumpkins	Number of Cattle	Sheep	Poultry
				Percentage					
1918	16.4	27.2	23.2	03.5	74.3	36.3	24.5	14.4	34.9
1930	-	-	23.0	-	77.0	-	51.1	10.8	-
1937	-	-	-	-	81.0	-	-	9.9	-
1950	-	-	18.8	01.7	46.4	-	41.0	11.7	31.3
1960	15.4	16.9	13.0	01.5	34.7	-	38.8	9.5	38.8
1991	14.4	15.2	-	-	-	-	-	-	-
2002	30.9	14.4	3.0	0.0	0.1	17.3	30.1	10.1	29.1

Sources: Liebenberg, Pardey, and Khan 2010 based on data from OCS 1919, 1932, and 1939; BCS 1952, 1963; CSS 1992; and Statssa 2005.

[4]A host of other initiatives were launched after the unification of South Africa to improve the productivity of the agricultural sector. Government provision of research, extension, training, and subsidized soil and veld conservation works were intended to help establish a vibrant farming community, often by way of farmer settlement programs and co-sponsored self-help schemes. Tenant farmers were provided with the necessary training and post-settlement extension support. In addition, the government made available start-up packages that included all the required means of production, with the repayment of these start-up costs (including the cost of purchasing the farmland) beginning after a five-year grace period (with interest for the five-year grace period capitalized into the purchase price). These schemes targeted new farm settlers according to their soldier status, racial status, and unemployment status, and incumbent farmers according to their farm size or farm profitability (or lack thereof). None of these attributes is a necessarily good indicator of the potential productivity and profitability of farms or the prospective social payoff to public investments in these schemes. Liebenberg (2010) provides new data on the public investments directed to farmer settlement and survival schemes in South Africa during the twentieth century.

of the country's cattle and poultry stock held by black farmers had contracted a little by 2000, although the sheep population on black-owned farms had marginally increased from 1960 to 2000.

In addition to the Land Reform and Restitution initiatives that were implemented beginning in 1994, the South African government established several programs to support black farmers. These include the Land Redistribution for Agricultural Development program (launched in 2000); the Comprehensive Agricultural Support Program that provides post-settlement support to targeted black farmers, whether they acquired land through private means or as part of a land reform program; and the Micro-Agricultural Financial Institutions of South Africa (MAFISA) program that extends micro-finance services to economically active poor rural households, small farmers, and agribusinesses. MAFISA provides loans to emerging farmers not served by the Land Bank, although the program is administered by the Land Bank on behalf of the Department of Agriculture (DOA 2009). The rollout of these programs to date has been slow, and it is too early to judge their effectiveness.

Taken as a group these agricultural indicators point to a long period of both physical and economic expansion in agriculture stretching from 1910 through to the 1950-1970 period. The 1950s and 1960s were a period of transition (at least for commercial agriculture), characterized by continued economic growth of agriculture, but growth that took place in the context of farm consolidation, a continued and perhaps even accelerating change in the composition of farm output, and a movement of labor out of agriculture as opportunities in other sectors of the economy competed for labor used within agriculture. These sizable structural shifts have important implications for—and in turn have no doubt been affected by—the amount and nature of research and development (R&D) and the accompanying technical and institutional changes striving to sustain economic development and productivity growth in agriculture going forward.

The quantity of total agricultural output grew at an average annual rate of 2.56% from 1911 to 2008. From 1911 to 1945, output grew by only 1.86% per year, accelerating to 3.58% annually over the following three decades, then slowing to just 1.52% per year for the period 1982-2000. Since 2000, output growth has rebounded, growing by 2.07% per year through to 2008. Over the almost one hundred years since 1911, growth in horticultural output (fruit and vegetables) outpaced that of field crops and livestock by almost 0.5% per annum (Figure 13.2). Field crop production kept pace with livestock output from 1911

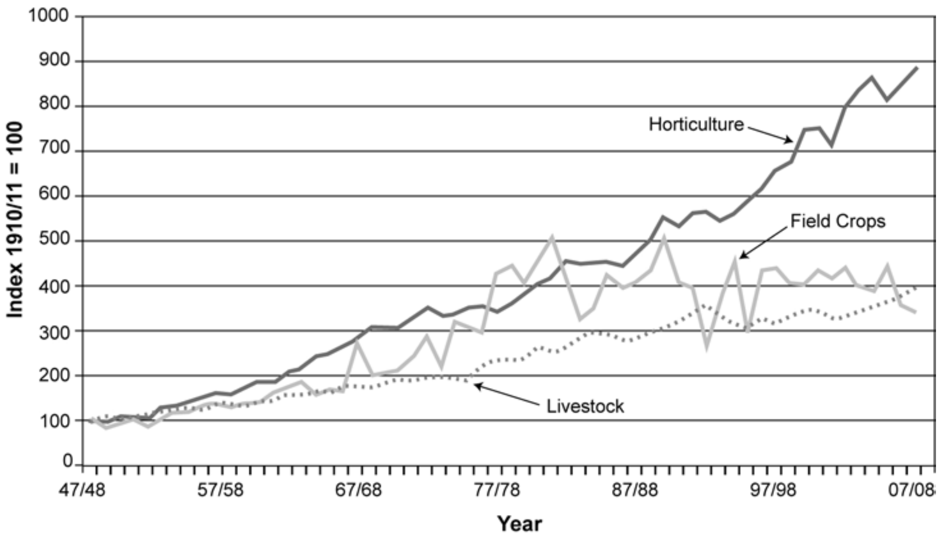

Figure 13.2. Quantity of agricultural output by sector, 1911-2008

Source: Liebenberg 2010.
Note: These series are Divisia (specifically Tornqvist) quantity indexes.

until the mid-1960s; during the subsequent two decades it grew at a faster rate than the livestock sector. However, during the period 1982-2008, field crop production grew by only 0.91% per year, lagging behind the corresponding growth in livestock output of 1.2% per year. Since 2000, growth in field crop production has substantially fallen behind the corresponding growth in livestock output, which increased by 2.02% per year.

The overall growth in total agricultural output is thus largely driven by strong growth in the horticultural sector, with comparatively slower growth in field crop output over more recent decades being a drag on the overall pace of growth of South African agriculture. Moreover, the rate of growth in agricultural output (and especially field crop production, which includes staple food crops such as wheat, corn, and grain sorghum) has fallen below the rate of population growth. South Africa's population grew by 2.43% per year from 1982 to 2008, compared with 1.52% per year for overall agricultural output (and just 0.91% per year for field crops).[5] Notably, the slowdown in both total output and crop output in South Africa in recent decades parallels similar trends in the United States, where total output grew by 1.63% per

[5]Although the rate of population growth has slowed in more recent years—to 1.34% per year since 2000—field crop production has slowed even more dramatically, to just 0.74% per year over the same period.

year during the 1980s (compared with 2.22% per year for the previous decade), slowing to 1.28% per year from 1990 to 2002 (Alston et al. 2010, Appendix Table 4-3).[6]

4. AGRICULTURAL INPUTS

Figure 13.3 gives an indication of the significant structural changes in farmland use in South African agriculture since 1910. Total farmed area grew to a peak of 91.8 million hectares in 1960, declining steadily to 82.2 million hectares in 1996, where it has since more or less stabilized. Total farm numbers followed a similar pattern, peaking in 1953 at 119,600, and declining at an average rate of 1.23% per year thereafter, so that by 2002 the number of farms had dropped to less than half the number that prevailed five decades earlier. The interplay between changing farm numbers and the total area in farms meant that average farm size declined during the first half of the twentieth century (from 1,019 hectares in 1910 to 730 hectares in 1952) and increased during the second half of the century, to average 1,640 hectares in 2000. Average farm size has continued to grow; in 2002 it was 1,833 hectares per farm.[7]

Figure 13.4 shows trends beginning in 1947/48 in the total cost shares of four agricultural input categories: labor, land, capital, and materials. Material

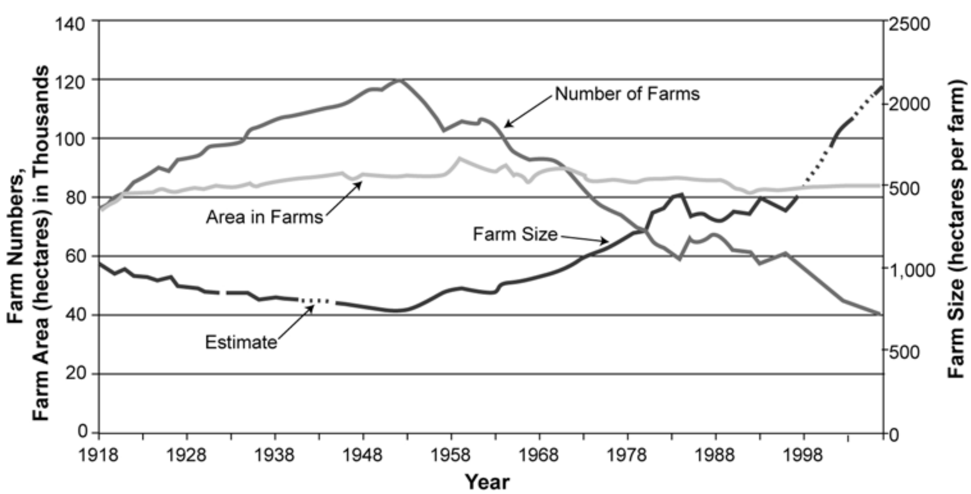

Figure 13.3. Number, total area, and average size of farms, 1918-2007

Source: Liebenberg, Pardey, and Khan 2010.
Note: Dashed sections of farm size plot indicate estimates (via interpolation).

[6]See also Chapter 8 in this volume.

[7]Preliminary agricultural census results indicate a continuing increase in average farm size, to about 2,000 hectares per farm, and a continuing decline in farm numbers, to 39,982 in 2009.

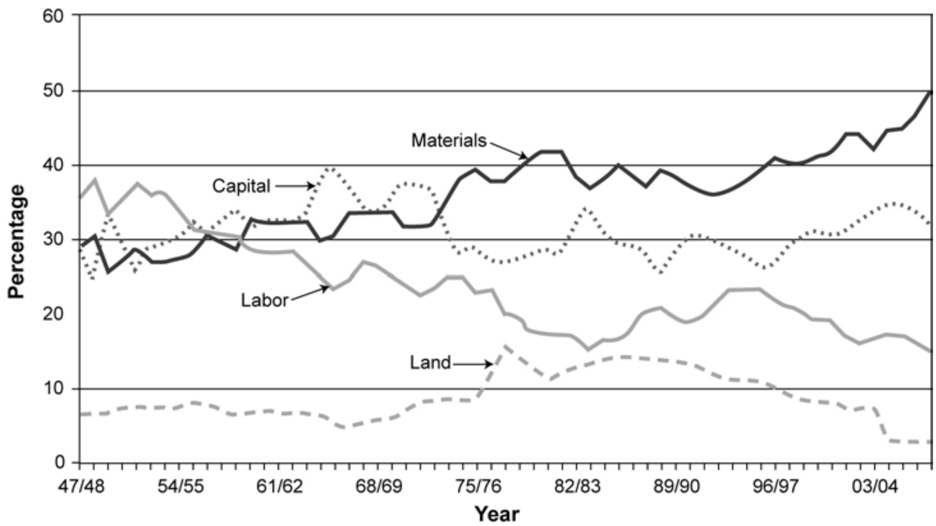

Figure 13.4. Input cost shares, 1947-2008

Source: Liebenberg 2010 based on data from DAS 2009.
Notes: In this compilation, land includes all land in agriculture (irrigated and rain-fed crops, permanent and planted pastures, and wood and forest land); labor includes owner-operator, hired labor (including domestic workers), and family labor; capital includes tractors, machinery, and implements, fixed improvements such as buildings erected, and development work undertaken; and materials includes dips and sprays, fuel, fertilizer, packaging, feed, and so on.

inputs (largely purchased from off-farm sources) have claimed an increasing share of total costs, around 30% in 1947/48 to 50% in 2006/07. Reported capital costs have fluctuated at around a 30% share of total costs over the same period, while labor inputs have steadily declined as a share of total costs, from almost 36% in 1947/48 to less than half that (15.1%) by 2006/07. At the beginning of the period, land costs accounted for 6.6% of total costs, growing to 15.5% by the mid-1970s, then shrinking to just 3.0% of total costs by 2006/07. Notably, Alston et al. (2010) reported land cost shares for the United States that followed a similar trend, starting at 17% of total cost in 1949, growing to 20% during the late 1970s and early 1980s (when land prices soared), then falling to 15% by 2002. However, according to these data, land cost shares are uniformly lower in South Africa compared with the United States, perhaps reflecting a much smaller share of cropped to total land in South Africa versus the United States along with a smaller share of that cropped land under irrigation.[8]

[8]According to DAS (2009, p. 5), 13.7% of South Africa's total land area is potentially arable, and around 69% of that arable area is only suitable for grazing. Moreover, a large share of the grazing area is in the semi-arid Karooveld.

An assessment of the magnitude of the cost share changes for land and labor in isolation reveals more substantive changes than are apparent by inspection of Figure 13.4. Looking in more detail at land costs, in nominal terms they grew by 0.5% per year during the period 1947-1959, when the total area under cultivation was still increasing, but they declined by 0.23% per year thereafter. Total labor costs fluctuated at around an average of R160.3 million during the 1960s but then declined by 3.08% per year until 1983. They increased during the period 1984-1987 but then began to decline and have continued to do so through 2007/08 (the last year for which data are presently available).

According to Thirtle, Sartorius von Bach, and van Zyl (1993), during the period ending in 1970, the cultivated corn area subject to summer rainfall expanded, as oxen were increasingly replaced by tractors. This spurred the expansion of average farm size (as measured by area per farm; see Figure 13.3) along with labor use as well as the use of chemical fertilizers and higher-yielding seed varieties (Payne, van Zyl, and Sartorius von Bach 1990). After 1970, the mechanization of crop harvesting activities through the increased use of combines began to alleviate a peak demand for labor at harvest time, thus contributing to a decline in overall labor use.

The general pattern of labor, land, and machinery use in agriculture in summer and winter rainfall areas evolved in parallel. The overall expansion of cultivated area was largely complete by 1947, with machinery increasingly substituting for labor throughout South African agriculture during this period. The Pass Laws of 1952 may have accelerated this ongoing factor substitution effect (especially during the late 1960s when the conditions of the Act were severely applied); however, other polices likely had a bigger effect.[9] Farmers were given access to cheap credit (which for periods of time involved negative real interest rates) and tax breaks that allowed capital equipment to be written off within the first year after purchase. By the end of the 1981-83 drought, the credit and tax concessions were largely gone, the price of gold had plummeted, and the rand was drastically devalued. These events had the combined effect of making

[9]The Pass Laws Act of 1952 was part of a historical series of such acts that in its earliest incarnation in 1797 sought to exclude all "natives" from the Cape Colony. The 1952 act made it compulsory for all black South Africans over the age of 16 to carry a "pass book" at all times. An employer was defined under the law and could only be a white person. The pass also documented permission requested and denied or granted to be in a certain region and the reason for seeking such permission. Under the terms of the law, any governmental employee could strike out such entries, basically canceling the permission to remain in the area.

domestic inputs, especially labor, much cheaper than (imported) capital items, causing a dramatic reversal of the historical trend during the late 1980s and into the early 1990s, with labor use increasing considerably as a substitute for relatively expensive capital during this period. Since then new legislation regarding security of land tenure for agricultural labor tenants working on large farms and the stipulation of minimum wages has again caused the sector to shed labor.

5. PARTIAL PRODUCTIVITY PATTERNS

Crop yields in South Africa are susceptible to significant year-on-year variation given that much of the production comes from rain-fed systems with average rainfall in the range of less than 250 mm per year in the west to 750 mm in the east, at the lower end of the ideal range for the crops in question (DOA 1957). On average, less than 80% of the country's total land mass receives an average annual rainfall of 750 mm or less, with 30% receiving less than 250 mm per annum. Nonetheless, the long-run crop yields summarized in Table 13.3 reveal substantial gains in average crop yields during the twentieth century. Corn yields increased more than 4-fold since the 1910s, wheat by 4.4-fold, and sorghum by more than 7-fold. Drought is a recurring reality of South African agriculture and had a detrimental impact on crop yields, especially during the first half of the 1930s, 1980s, and 1990s. The growth in yields during the first half of the twentieth century was associated with increased mechanization and increased use of improved seeds (with a corresponding marked increase in the use of chemical inputs, including fertilizers, herbicides, and pesticides) helping to also spur crop yield growth after the 1960s.

The livestock "yields" presented in Table 13.3 are harder to interpret and may reflect the difficulty of meaningfully measuring productivity in these sectors. For instance, the decline in the average slaughter weight of pigs reflects a largely demand-driven shift to leaner pork products. The slaughter weight of sheep also declined steadily after the Second World War, from an average carcass weight of 39.1 kg per head during the 1930s and 1940s to just 19.8 kg per head in more recent years. Again the shift in consumer preferences has played a role—with leaner and much younger (i.e., lamb versus mutton) cuts of meat being preferred—but massive structural changes in the sheep industry have also played their part. As wool demand slackened over the past three decades or so, growers shifted from sheep-for-wool to sheep-for-meat systems of production, with associated shifts in the average age of the sheep population (i.e., a move to younger and

Table 13.3. Average yields for selected commodities for various periods

	Cattle	Sheep	Pigs	Corn	Wheat	Grain Sorghum
		(kg/head)			(kg/ha)	
Five-year averages centered on						
1911/12				765	592	445
1920/21	235	39		737	501	580
1930/31	205	30	90	465	717	952
1940/41	251	29	85	771	488	963
1950/51	226	33	78	826	518	987
1960/61	223	29	81	1,235	590	872
1970/71	217	25	64	1,480	811	1,201
1980/81	215	25	66	2,082	1,103	1,816
1990/91	228	22	61	2,074	1,460	2,360
2000/01	231	18	62	2,606	2,449	2,822
2005/06	259	20	74	3,326	2,583	3,272
Average annual growth (percent per year)						
1910/11-1929/30				-1.29	0.30	-1.43
1930/31-1949/50	0.82	0.59	-0.76	3.39	-2.72	3.29
1950/51-1969/70	-0.26	-1.25	-1.07	2.04	1.29	-1.89
1970/71-1989/90	0.53	-0.26	0.13	0.28	2.33	2.27
1990/91-2007/08	0.98	-0.01	1.19	4.58	3.34	3.03
1920/21-1949/50	0.75	0.03	-0.58	1.95	-2.10	4.32
1950/51-2007/08	0.17	-1.03	-0.35	2.05	3.17	2.53
2000/01-2007/08	2.76	2.34	4.29	4.63	2.64	2.46

Source: DAS 2009.
Notes: Corn and sorghum includes only the crop grown for grain, and wheat includes all types of wheat (mainly durum). Animal weights are slaughtered weights. Growth rates were computed by the natural log regression method.

hence smaller animals), and with direct consequences for average carcass weights. As evidence of this trend, merino sheep accounted for up to 80% of the national sheep herd in the 1960s (and up to 86% if dual-purpose breeds are also included), whereas now the merino share has declined to 50% (or 71% if dual-purpose breeds are included). The total number of sheep in the country has also declined from 37.4 million head of sheep in 1966 to 21.9 in 2008, with numbers of merino sheep declining from 28.3 million to 11.6 million over the same period (DAS 2009).

From 1911 to 2008, land productivity grew at an average annual rate of 2.49% per year, slightly slower than the corresponding rate of labor productivity growth, which averaged 2.83% per year (see Figure 13.5). Throughout the twen-

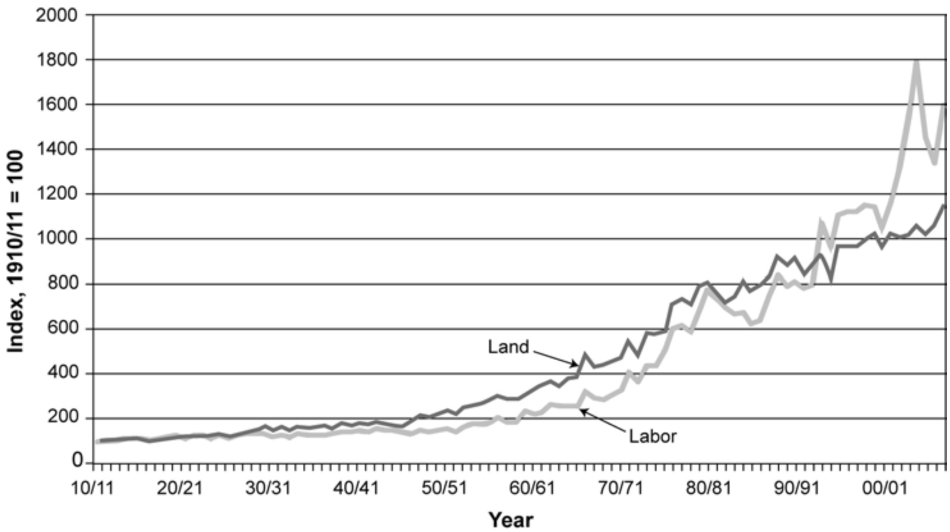

Figure 13.5. Agricultural labor and land productivity in South Africa, 1911-2008

Sources: Authors' calculations based on data from DAS 2009 and Statssa 2009.
Notes: Labor data were adjusted to consistently include seasonal labor. These series are Divisia (specifically Tornqvist) quantity indexes.

tieth century there were three phases of distinct growth patterns in these two partial productivity measures. During the pre-WWII years (from 1911 to 1940), land productivity grew by 1.95% per year, double the corresponding annual rate of growth of labor productivity (0.89% per year). The rate of growth of both land and labor productivity picked up over the subsequent four decades following WWII (i.e., the period 1947-1981), averaging an impressive 4.91% per year for labor productivity and 4.17% per year for land productivity. Since then, productivity growth rates for both land and labor have slowed considerably, down to 2.67% per year for labor, and only 1.46% per year for land productivity.

Figure 13.6 draws on Food and Agriculture Organization (FAO) data to place land and labor productivity measures for South Africa into a broader African context. Here we use the graphical technique developed by Hayami and Ruttan (1971) in which the horizontal axis measures labor productivity (in logarithms) and the vertical axis measures land productivity (in logarithms). Productivity loci for five regions in sub-Saharan Africa plus Nigeria and South Africa are included. The productivity loci were formed by taking a ratio of the value of aggregate output and the respective land and labor inputs. Output is an estimate of the total value of agricultural output (spanning all crops and live-

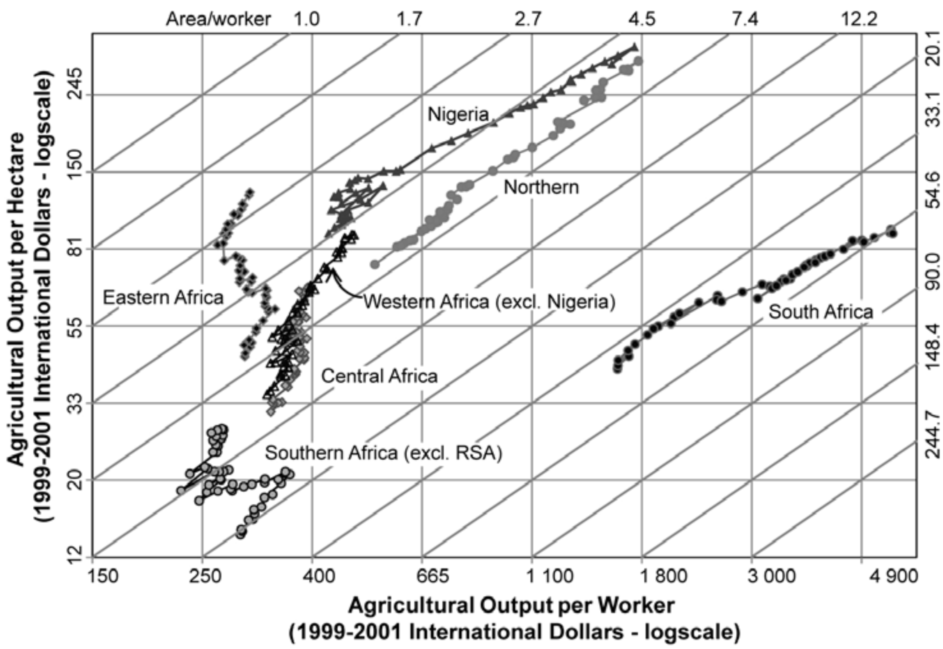

Figure 13.6. Agricultural labor and land productivity in sub-Saharan Africa, 1961-2007

Source: Calculated from data obtained from FAOSTAT Database.
Notes: Central Africa includes Burundi, Cameroon, Cent Afr Rep, Chad, Congo Dem R, Congo Rep, Eq Guinea, Gabon, Rwanda, Sao Tome Prn, Sudan; Eastern Africa includes Comoros, Djibouti, Eritrea, Ethiopia, Ethiopia PDR, Kenya, Madagascar, Malawi, Reunion, Seychelles, Somalia, Tanzania, Uganda; Southern Africa (excluding South Africa) includes Angola, Botswana, Lesotho, Mauritius, Mozambique, Namibia, Swaziland, Zambia, Zimbabwe; and Western Africa (excl. Nigeria) includes Benin, Burkina Faso, Cape Verde, Cote d'Ivoire, Gambia, Ghana, Guinea, Guinea Bissau, Liberia, Mali, Mauritania, Niger, Senegal, Sierra Leone, Togo. See text for data construction and plotting details. The land-labor ratio is constant along each grey diagonal line, and values for those ratios are given at the terminus of the respective diagonal line on the top and right axes.

stock commodities) expressed in 1999-2001 average purchasing power parity agricultural prices obtained from FAO (FAOSTAT Database). Land is a measure of harvested and permanently pastured area, and labor is a head count of the total economically active workers in agriculture. These ratios were then scaled by the corresponding value ratios of output and input in the base year 1961, and the natural logarithms of the scaled index ratios were then taken.[10] Since both axes are measured in natural logarithms a unit increase in either direction is in-

[10]The output and input indexes are all normalized to a value of 1.0 in base year 1961, which means the productivity paths for each region would begin from the same value if they were not scaled by the respective base-year value ratios.

terpreted as a proportional increase in land or labor productivity, and the length of the productivity locus is an indication of the average annual rate of change in productivity. Most, but by no means all, of the productivity paths move generally (but not uniformly) in a northeasterly direction, starting in 1961 and ending in 2005, indicating productivity growth. The diagonals indicate constant labor-to-land ratios. As the productivity locus for a particular country or region crosses a diagonal from left to right, it indicates a decrease in the number of economically active workers in agriculture per harvested acre in that region.

The South African and Nigerian productivity loci follow distinctly different paths than the other regions of sub-Saharan Africa plotted in Figure 13.6. Both countries had increases in land and, especially, labor productivity that were at considerably higher rates than the rest of Africa. Moreover, the value of output per unit of labor in 2007 for both countries was also considerable higher than the rest of Africa: $5,663 per worker in the case of South Africa and $1,576 per worker for Nigeria compared with an average of $641 per worker for the rest of Africa. South Africa is distinctive in that it is the only entity depicted in Figure 13.6 for which the land-labor ratio increased to any great extent over time (implying more pronounced growth in labor versus land productivity): from 39.1 hectares per worker in 1961 to 56.9 hectares per worker in 2007. In Nigeria, the land-labor ratio (starting from a much smaller initial value) increased a little: from 4.36 to 5.27 agricultural hectares per worker over the comparable period. In almost all the other regions depicted, 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. Thus the horizontal spans of the productivity loci were smaller than their vertical spans so that land-labor ratios were smaller on average in 2007 than they were a quarter of a century earlier.

West Africa (excluding Nigeria) is an exception compared with the general rest-of-Africa (i.e., sub-Saharan Africa minus South Africa and Nigeria) productivity pattern. This region saw labor productivity grow by 0.78% per year from 1961 to 2007 (compared with 2.68% per year for South Africa and 3.24% per year for Nigeria). Labor productivity in East Africa barely changed, and in Southern Africa (excluding South Africa) it declined from $291 per worker in 1961 to a lowly $255 per worker in 2007. These productivity trends speak to the dismal record of poverty and chronic food insecurity that befall a large share of the populations in these parts of Africa.

Perhaps ironically, these dismal labor productivity trends in Central, Eastern and Southern Africa (excluding South Africa) belie their comparatively rapid rates of growth in total output. These three regions report real agricultural output growth in the range of 1.35% to 2.85% per year over the period 1961-2007, in some instances much faster than the comparative rates of growth in total output for South Africa, which averaged just 1.65% per year. However, 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. Thus, the poor labor productivity performance of Central, Eastern, and Southern Africa (excluding South Africa) reflects a failure of labor to leave agriculture for gainful employment elsewhere in these economies rather than a comparatively low rate of growth in agricultural output. Moreover, although the land area in agriculture has continued to expand in these parts of Africa, it has done so at a rate less than the rate of growth in agricultural workers. With land-labor ratios ranging from 2.33 to 9.34 hectares per worker, it is difficult to envisage raising output per worker to substantial levels, especially given the generally poor rural infrastructure and other market and environmental constraints that limit the transition to higher-valued forms of agricultural output.

6. MULTIFACTOR PRODUCTIVITY IN SOUTH AFRICAN AGRICULTURE

Table 13.4 reports a series of measures of aggregate input, output, and multifactor productivity (MFP) growth for South African agriculture over the period 1947-2007. The bottom half of the table includes estimates reported in several studies. They indicate a large disparity in the measured rates of MFP growth for South African agriculture, with no apparent consensus or pattern emerging from or evident in the different measures. Some of these differences may be attributable to differences in the range of years covered by each study, but differences in data coverage and treatment no doubt play a role too, making an overall assessment of these studies problematic.

The upper half of Table 13.4 reports an effort by the authors to extend the aggregate input, output, and MFP measures first reported by Thirtle, Sartorius von Bach, and van Zyl (1993) for the period 1947-1991 and updated in Schimmelpfennig et al. (2000) for the period 1947-1997. Thirtle, Sartorius von Bach, and van Zyl indicate that their aggregate output measure consists of a Divisia aggregation of three pre-aggregated groups of outputs, namely, crops, horticul-

Table 13.4. Growth of agricultural output, input, and MFP indexes, various estimates, 1947-2008

	Attributes of Study					Study Source	
Period	Output	Input	MFP	Labor	Land	Authors	Date
	(percent per year)						
1947-1971	3.43	2.81	0.62	3.27	3.36	This study	2010
1971-1989	3.28	0.70	3.98	4.91	3.50	This study	2010
1989-2008	0.95	0.95	0.01	3.22	1.11	This study	2010
1947-2008	2.68	1.20	1.49	3.87	2.78	This study	2010
1947-1991			1.3			Thirtle, Sartorius von Bach, and van Zyl	1993
1947-1997			1.3			Schimmelpfennig et al.	2000
1965-1994			0.28			Nin, Arndt, and Preckel	2003
1952-2002			1.35			Conradie, Piesse, and Thirtle	2009a

Sources: See text for details of entries in the upper half of the table.

ture, and livestock. The input index consists of an aggregation of measures of land, labor, intermediate inputs (i.e., packing fuel, fertilizer, dips and sprays, and other non-farm items), and capital inputs (i.e., fixed improvements and machinery). The update reported here in Table 13.4 and Figure 13.7 spans the period 1947-2008. It was developed by extending the Schimmelpfennig et al. 1947-1997 series, and in so doing we sought to faithfully deploy the same methods, data types, and sources used in the earlier compilations.[11]

According to this measure, South African MFP grew, on average, by 1.49% per year from 1947 to 2008. The 1970s and 1980s had the highest rate of growth for the period studied, an impressive (and perhaps questionable) 3.98% per year. This is substantially higher than the 0.62% per year rate reported for the immediate post-WWII decades. Notably, MFP was stagnant during the period 1989-

[11]The authors thank Colin Thirtle for kindly providing the data he and colleagues developed for the 1947-1997 period. Liebenberg (2010) reports an entirely new series constructed from different data sources and using different methods. For example, Liebenberg found that historical capital input and livestock inventory estimates were compromised by especially low participation rates in the national agricultural censuses conducted since 1992/93. DOA statistical agencies subsequently adopted alternative estimation methods that resulted in significant changes to the previously reported national capital and livestock inventory estimates back to the 1980s (personal communication with D. Blignaut, Head of Regional Production Statistics, DOA, in 2009). Liebenberg is also making an effort to correct for significant inconsistencies in the officially reported data on agricultural labor attributable to inconsistencies in the treatment of seasonal, domestic, and family labor.

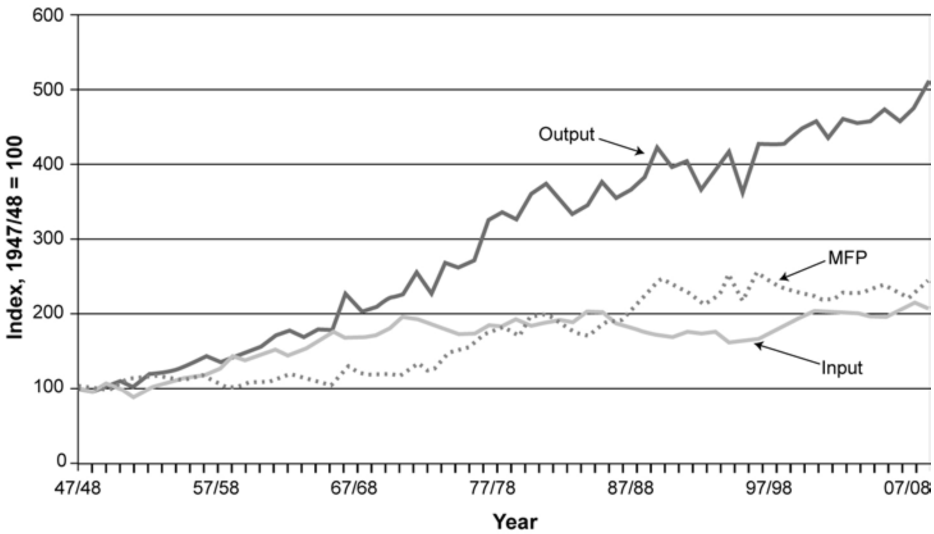

Figure 13.7. Agricultural output, input, and MFP indexes, 1947-2008

Source: See text for details.

2008, apparently owing to a decline in the rate of output growth coupled with an increase in the rate of input use in agriculture.

Recent studies by Conradie, Piesse, and Thirtle (2009a,b) extend the earlier methods used by Thirtle and colleagues to compile regional estimates of aggregate input, output, and MFP growth for South African agriculture (see Table 13.5). They focused on the Western Cape region of the country. This region has distinctive agro-climatic attributes: specifically, it is the only region within South Africa that experiences winter rainfall, and so its agricultural output is dominated by deciduous fruit and wine grapes whereas output in the rest of the country consists mainly of field crops and livestock products.

Conradie, Piesse, and Thirtle (2009b) estimate that during the period 1952-2002, MFP in the Western Cape grew on average by 1.22% per year. The regional rate of growth is roughly the same as the long-run measured rate of growth in MFP at the national level. However, there are marked disparities in the regional and national growth rates for specific sub-periods. For example, from 1971 to 2002, the Western Cape region saw productivity growing at 0.89% per year, less than half the corresponding rate of growth at the national level (which Conradie, Piesse, and Thirtle [2009b, p. 12] put at more than 2% per year). Again differences in data sources and treatment may account for some of the disparities, but it is also likely that differences in the composition of output and inputs and other

Table 13.5. Regional growth rates (%) of agricultural output, input, and MFP indexes, 1952-2002

	1952-2002			1952-1971			1971-2002		
Regions	**Input**	**Output**	**TFP**	**Input**	**Output**	**TFP**	**Input**	**Output**	**TFP**
Western Cape	2.1	3.32	1.22	2.71	3.96	1.25	1.85	2.74	0.89
Karoo Region	0.17	-0.55	-0.72	0.27	2.12	1.85	-0.85	-1.32	-1.14
Olifants River Valley	2.8	4.52	1.72	3.57	4.16	0.58	2.53	4.4	1.87
Breede River Valley	2.57	4.79	2.22	3.29	3.2	-0.08	2.28	5.79	3.51
Swartland Region	2.77	3.3	0.53	3.61	3.17	-0.44	2.29	4	1.71
Malmesbury-Moorreesburg	3.17	3.54	0.37	4.61	4.13	-0.48	2.15	3.15	0.99
Piketberg	2.54	3.37	0.83	2.63	2.44	-0.19	2.84	5.61	2.77
Vredenburg-Hopefield	1.3	1.85	0.54	1.85	5.62	3.77	0.85	0.06	-0.79

Source: Conradie, Piesse, and Thirtle 2009b, Table 2.

factors play a role in these regional differences, as they do regarding the considerable national versus state differences in productivity patterns reported for the United States by Alston et al. (2010).

In Table 13.6 we summarize estimates of MFP growth for a series of other studies for other countries in sub-Saharan Africa. Extracting plausible patterns from this evidence is especially problematic, in part because of substantive differences in data and methods, but also given the paucity of studies that are available. One fairly consistent finding is that the reported rates of MFP growth in Africa are generally low compared with those reported for other countries worldwide included in this book and elsewhere. That said, differences in sectoral coverage and analytical methods may account for the very considerable differences in reported growth rates for similar periods in the studies by Alene (2009) and Ludena et al. (2006). The Africa-wide results of Alene using Malmquist methods concord with those reported earlier (Table 13.4, upper half) for South Africa using Divisia aggregation approaches, to the extent they suggest that the rate of MFP growth has slowed in recent years. However, the "sequential Malmquist" results from Alene show no evidence of a slowdown. Irz and Hadley (2003) found a marked difference in MFP growth rates for commercial versus traditional farmers in Botswana, highlighting the fact that aggregating over different types of farmers may pose substantive measurement and interpretation challenges analogous to those confronted when forming national versus state or provincial estimates.

7. CONCLUSION

South African agriculture appears to have sustained a competitive edge during the decades prior to the late 1980s, with strong growth in agricultural exports and more muted, but still pronounced, growth in net agricultural trade surplus. However, the country's agricultural exports and net trade balances have declined precipitously in more recent years. These trade trends are loosely concordant with changes in the pattern of MFP growth for South Africa, which grew at much slower rates in more recent years compared with earlier decades.

The rate of growth in agricultural output has also slowed since the 1980s, largely as a result of a slowdown in the rate of growth in field crop production. Indeed, agricultural output growth in South Africa (and, for that matter, Southern Africa) has lagged behind the rest of Africa in recent decades, even though the country's agricultural productivity growth has historically outpaced produc-

Table 13.6. Sub-Saharan Africa multifactor productivity growth rates, various studies

Authors	Date	Region	Crop/Industry	Methodology	Sample Period	Average Annual Growth Rate (%/year)
Irz and Hadley	2003	Botswana	Agriculture:	Input Distance		
			Traditional Farmers		1979-1996	-2.3
			Commercial		1968-1990	1.16
Dhehibi and Lachaal	2006	Tunisia	Agriculture	Tornqvist	1961-2000	3.6
Ludena et al.	2006	Middle East & North Africa	Crops	Malmquist	1961-2000	-0.03
			Ruminants		1961-2000	-0.02
			Nonruminants		1961-2000	0.64
			Average		1961-2000	0.03
		Sub-Saharan Africa	Crops		1961-2000	0.15
			Ruminants		1961-2000	0.36
			Nonruminants		1961-2000	0.5
			Average		1961-2000	0.21
Alene	2009	Africa	Agriculture	Malmquist	1970–1980	-0.9
					1981–1990	1.4
					1991–2004	0.5
					1971-2004	0.3
				Sequential Malmquist	1970–1980	1.4
					1981–1990	1.7
					1991–2004	2.1
					1971-2004	1.8

Notes: The input distance function used by Irz and Hadley (2003) is a conventional measure of the largest factor of proportionality by which the input vector x can be scaled down to produce a given output vector y with the technology that exists at a particular time t. The premise of the sequential Malmquist TFP index used by Alene (2009) is that past production techniques are also available for current production activities. The distance metrics in this instance are calculated using linear programming techniques formulated with respect to a "sequential" technology frontier.

tivity growth elsewhere in the continent. The 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 change too. Notwithstanding high rates of rural unemployment, the evidence reported in this chapter indicates that South African agriculture has substantially increased its use of material inputs and continued to invest significantly in capital inputs while the use of labor in agriculture has declined.

South African agriculture is important in a regional and continental context. In 2006 it accounted for 43.6% of the agricultural GDP of Southern Africa and 5.93% of the agricultural GDP for sub-Saharan Africa as a whole (World Development Indicators Database). Thus the recent and substantive declines in the pace of South African MFP growth, when coupled with the persistence of historically low rates of labor productivity throughout the rest of Africa, are causes for real concern. It is 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. Indeed, the evidence presented here indicates that the rate of MFP growth in South African agriculture lost considerable ground in recent years and is now well below the country's corresponding rate of population growth. The same holds true for Africa generally (at least for the land and labor productivity metrics presented here). These realities make it imperative to carefully and creatively, and with some urgency, rethink and revitalize those rural development options that promote long-term productivity growth, most notably investments in, and the incentive structures that affect, agricultural R&D. It will take time to turn around these poor productivity performances, and so the policy choices made now, as well as the details of their implementation over the next few years, will determine the destiny of the country's (and the continent's) agricultural sector for a significant share of the century that lies ahead.

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CHAPTER 14

The Agricultural Sector in Argentina: Major Trends and Recent Developments

Sergio H. Lence

1. INTRODUCTION

Historically, Argentina has been among the world leaders in the production and/or export of agricultural products. The main reason for this is that it is a country relatively sparsely populated but richly endowed with natural resources for production agriculture. According to data from the Food and Agriculture Organization (FAO) (FAOSTAT database), in 2006 Argentina accounted for only 0.59% of the world's population, but for a much higher 2.10% of the world's total land area. Furthermore, Argentina's shares of the world's arable land and the planet's area with permanent meadows and pastures were even higher, at 2.23% and 2.96%, respectively.

As shown in Table 14.1, Argentina produced 8.4% of world agricultural output and accounted for 2.9% of world agricultural trade over the period 2005-07. Such figures make Argentina the eighth-largest producer and the twelfth largest exporter of agricultural commodities in the world. Argentina's much smaller share of world exports (2.9%) compared to its share of world output (8.4%) is largely explained by the fact that Argentina tends to export commodities with relatively low value-added levels. Commodities for which the country is particularly relevant in world markets are soybeans and its associated products, soybean oil and soybean meal. Argentina is the top exporter of soybean oil and soybean

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Table 14.1. Argentina's world share and world ranking in production and exports of selected agricultural commodities, average 2005-2007

	Production		Exports	
Commodity	World Share (%)	World Ranking	World Share (%)	World Ranking
Total agricultural products	8.4	8	2.9	12
Crop products				
Apples	2.0	11	2.8	11
Corn	2.6	5	10.8	2
Grapes	4.3	8	1.3	16
Lemons and limes	10.7	3	11.2	3
Soybeans	19.3	3	13.7	3
Soybean meal	17.4	3	36.1	1
Soybean oil	17.4	3	46.9	1
Sunflower meal	13.9	3	17.5	2
Sunflower oil	13.9	3	19.8	2
Sunflower seed	12.3	3	3.3	9
Wheat	2.4	13	6.7	7
Wine	5.6	5	1.7	11
Animal products				
Bovine meat	4.8	4	5.2	7
Cow milk	1.8	15		
Dairy products			1.4	16
Poultry meat	1.4	13	0.8	19

Source: All figures calculated from FAOSTAT data.
Notes: Production shares and rankings based on physical units, except for "Total Agricultural Products" which are based on quantities valued at the 1999-2001 average international commodity prices. Export shares and rankings based on actual dollar values of traded commodities.

meal, with 46.9% and 36.1% of the world's export market, and the third-largest exporter of soybeans. For all three commodities, Argentina ranks third among all producers, with almost one-fifth of world output. In addition, Argentina is the world's second-largest exporter of corn, sunflower meal, and sunflower oil. The country is also the fourth-largest beef producer, with 4.8% of the world's output, but it only ranks seventh among beef exporters. A major reason for this is that Argentineans consume the most beef per capita of all world consumers of beef, averaging 54 kilograms per capita per year over 2001-03 (FAOSTAT).

Given the relevance of Argentina to world agricultural markets, an in-depth investigation of the recent evolution of its agricultural sector should be of interest. Better knowledge of the main developments that have characterized Argentinean agriculture in the past should help in making inferences about its potential course for the future. In the process, one should also gain a better understanding of the likely effects on the world markets of the commodities for which Argentina is or can be a significant supplier. Therefore, the purpose of this chapter is to analyze the major output, export, and productivity trends experienced by Argentinean agriculture in recent decades, and to study the main drivers behind such developments.

First, general background information is provided to put Argentinean agriculture in perspective. Second, the evolution of agricultural policies in Argentina and their impacts are discussed. Third, the most important developments in Argentinean production agriculture since 1990 are analyzed. Fourth, the major trends in productivity for individual factors of production are examined. This is followed by a review of the measures of Argentina's total factor productivity growth estimated by the recent literature.

2. ARGENTINEAN AGRICULTURE IN CONTEXT

This section provides basic information about Argentinean agriculture, to aid in the analysis provided later. First, the role of agriculture in Argentina's economy is addressed, which should be useful in understanding the policies affecting the sector. This is followed by a general characterization of the country's agriculture.

2.1. Agriculture and Argentina's Economy

Table 14.2 reports the evolution of some key economic indicators for Argentina since 1960, as well as some indicators of the role of the agricultural sector in the entire economy. With an average gross domestic product (GDP) of about U.S.$5,600 per capita in 2005-07, Argentina is classified as an upper middle-income economy by the World Bank. Consistent with the country's moderate level of development, the services sector is the most important contributor to GDP, followed by the industrial sector. As the economy has developed over time, agriculture's share of GDP has tended to fall. However, this share has almost doubled since 2000, and over 2005-07 agriculture accounted for a sizable 9% of GDP. Agriculture has accounted for an even larger share of total employment, indicating that wages in the sector have been smaller than wages in the services and manufacturing sectors.

The sector is estimated to have contributed almost one-fifth of Argentina's GDP in 2003-05 if activities directly related to primary agriculture are included (Fundacion Producir Conservando 2007). In 2003, about 5.59 million people

Table 14.2. Evolution of general and agricultural economic indicators for Argentina, 1960-64 through 2005-07

	1960-64	1965-69	1970-74	1975-79	1980-84	1985-89	1990-94	1995-99	2000-04	2005-07
Population (million)	21.3	22.9	24.8	26.9	29.0	31.2	33.5	35.7	37.6	39.1
Gross domestic product (GDP) per capita (current U.S. dollars)	n.a.	1,211	1,813	2,142	2,921	3,289	6,294	7,879	4,982	5,616
Agricultural share of employment (%)	19	17	15	14	13	12	12	10	9	n.a.
Agricultural share of GDP (%)	n.a.	10	11	8	8	8	6	5	7	9
Agriculture and food share of merchandise exports (%)	93	90	79	74	73	65	60	53	48	48
Agriculture and food share of merchandise imports (%)	13	17	14	11	9	9	7	7	6	3
Net exports as percentage of exports plus imports of agriculture and food (%)	79	73	73	79	81	85	78	76	85	87
Agriculture and food index of revealed comparative advantage[a]	3.2	3.5	3.6	3.8	4.4	4.4	4.7	4.9	5.4	6
Exports of goods and services as percentage of GDP (%)	n.a.	n.a.	n.a.	12	12	10	8	10	18	25

Sources: Sandri et al. 2007 for data up to and including 2004. For 2005-07, data on population, GDP per capita, agricultural share of GDP, and exports of goods and services as a percentage of GDP were obtained from the World Bank's World Development Indicators. Other figures for 2005-07 were calculated from the World Trade Organization's statistical database (http://www.wto.org/english/res_e/statis_e/statis_e.htm).

[a]Agriculture and food share of merchandise exports for Argentina as a ratio of this share for the world.

were either directly employed by the food and agriculture sector or indirectly employed by it through upstream and downstream linkages, amounting to about one-third of the country's total employment in 2003 (Llach, Harriague, and O'Connor 2004). Furthermore, the taxes paid by agriculture and the activities directly related to it accounted for about 40% of the total taxes collected by the Argentinean government in 1997-2001, and for more than 45% in 2002-05 (Fundacion Producir Conservando 2007).

The importance of agriculture to Argentina's economy is most evident when examining the country's balance of trade (see Table 14.2). In the 1960s, exports of agricultural and food products amounted to more than 90% of total merchandise exports. This share has steadily declined since then, but over the period 2000-07 almost half of the exports consisted of agricultural and food products. In contrast to exports, imports of agricultural and food products have traditionally been a small percentage of total merchandise imports, averaging only 3% over 2005-07. With net exports well in excess of 80% of the sum of exports plus imports of agricultural and food products, Argentina is clearly a net supplier of such products in world markets.

The large magnitude of exports from the agricultural sector is underscored by the fact that total merchandise exports were equivalent to 25% of Argentina's GDP in 2005-07. The agriculture and food index of revealed comparative advantage, calculated as the agriculture and food share of merchandise exports for Argentina relative to the world food share, averaged a value of six in 2005-07. This considerably large index value provides strong evidence that the country's relative strength lies in producing and exporting agricultural and food products as opposed to manufactured goods. Further, the index has steadily increased, from slightly above three in 1960-64, suggesting that, if anything, the comparative advantage of Argentina's agricultural sector has risen over time.

In addition to its important contributions to GDP, employment, trade, and fiscal revenues, the agricultural sector provides three key staples of the Argentinean diet, namely, bread, beef, and milk. As pointed out earlier, on a per-capita basis, Argentina is the world's leading consumer of beef. Per capita wheat consumption of bread, which averaged 119 kilograms per capita per year in 2001-03, is among the highest in the world (e.g., only 4 out of the 66 countries classified as high-income economies by the World Bank ranked higher). Per capita consumption of dairy products is also large and significantly above the world average. The large incidence of wheat, beef, and milk in the domestic diet has made these products traditionally sensitive from a policy-making standpoint. For example, starting in 2007, bans and other types of restrictions on their export have been imposed in an attempt to ensure ample supplies and low prices in the domestic market (IICA 2007).

2.2. A Succinct Characterization of the Agricultural Sector

According to FAO's production index number, slightly over 60% of Argentina's agricultural output value in 2005-07 originated from crops and almost 40% from livestock. As depicted in Figure 14.1, the value of crop production has increased at a significantly faster rate than the value of livestock output over the last few decades, implying that the relative incidence of livestock in the sector has declined steadily over time. The relative incidence of crops in exports is even larger, as crops and their products accounted for 80% of the total exports by the sector in 2005-07. As for production, the export share of livestock has exhibited a clear downward trend.

Figure 14.2 shows the breakdown of the value of the sector's output by commodity for the years 2005-07. The most striking feature of the graph is the high concentration of the value of output in a handful of commodities. In particular, beef and soybeans alone contribute more than half of the value of Argentina's agricultural production, each accounting for slightly over a quarter of the total value. They are followed by wheat, corn, and milk, with shares of 8%, 6%, and 5%, respectively. The value of the top five commodities makes up approximately three-fourths of the total value of agricultural output.

Underlying the aggregate index trends displayed in Figure 14.1 are substantial changes in the trends for individual commodities. In the case of crops, Figure 14.3 shows that corn and wheat output grew at a relatively constant pace since the 1960s. Output of sunflower seed, in contrast, increased sixfold between the late 1970s and 2000, only to decline by almost half since 2000. Among crops, the most important development was the explosive growth of soybeans, which went from being essentially unknown in the early 1970s to becoming by far the most important crop. In 2005-07, more than half of the crop area and about 45% of the value of crops produced corresponded to soybeans. The evolving patterns in crop output were induced by changes in the relative profitability of the various crops, largely arising from shifts in world supply and demand, the introduction of new technologies, and domestic agricultural policies. The latter two topics are discussed in greater detail in later sections.

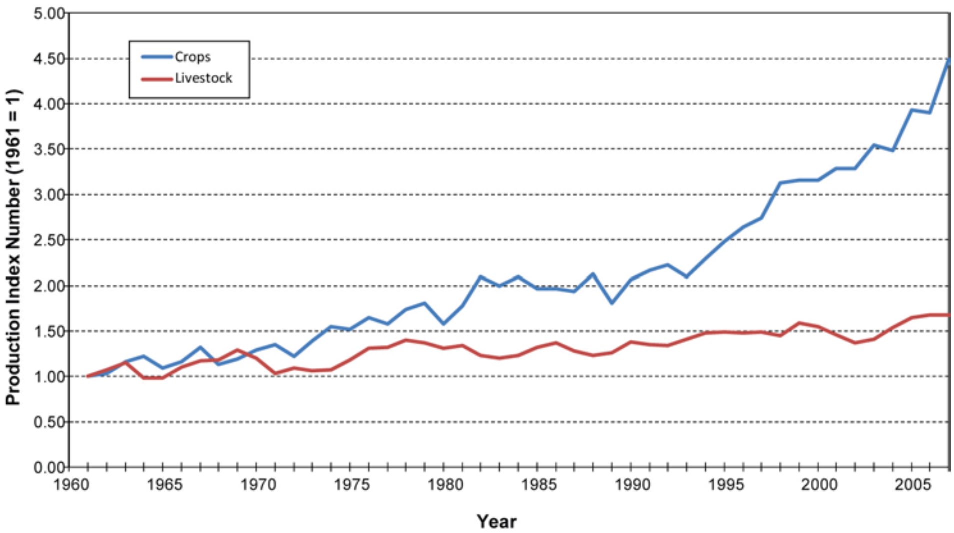

Figure 14.1. Production index numbers for agricultural production in Argentina, 1961-2007

Source: Prepared using data from FAOSTAT.

Notes: Production indexes are the sum of price-weighted quantities of different agricultural commodities relative to the year 1961. The prices used for weighing the production quantities of each commodity are the average international commodity prices over 1999-2001.

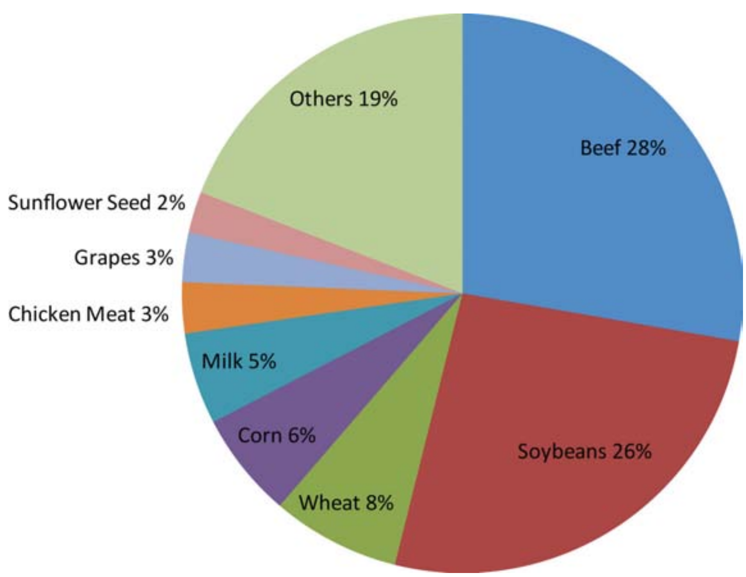

Figure 14.2. Commodity shares of the total value of agricultural production in Argentina, 2005-2007

Source: Prepared using data from FAOSTAT.

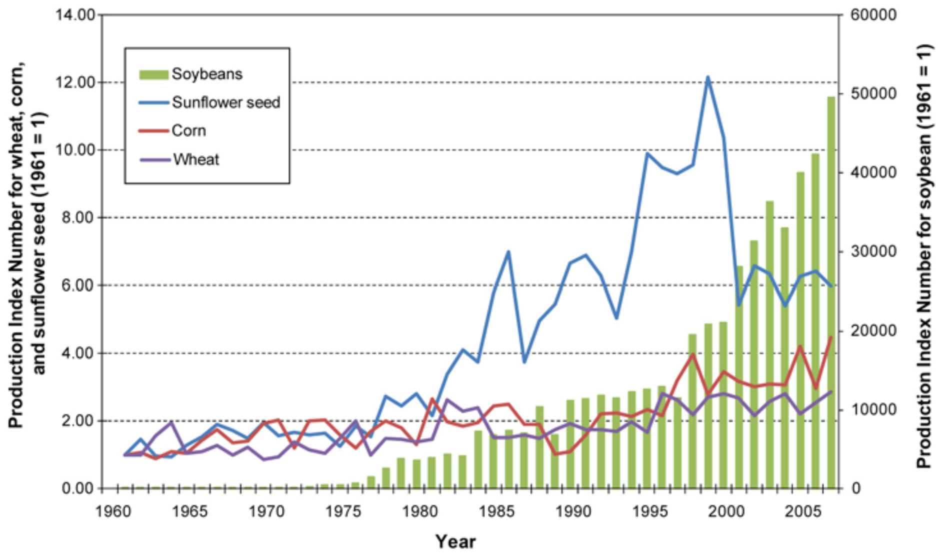

Figure 14.3. Production index numbers for major crops in Argentina, 1961-2007

Source: Prepared using data from FAOSTAT.
Note: Production indexes are calculated as the quantities produced relative to the year 1961.

Subsectors of the livestock industry fared quite differently (see Figure 14.4). Since 1961, sheep and goat meat production declined by two-thirds. Production of cattle meat has shown no clear trend since the late 1970s, and the same is true of pig meat output. Milk production, in contrast, more than doubled between 1961 and 2007. Over this period, the livestock industry with the highest growth was poultry, as it increased more than 25-fold. The lack of growth in beef production over the last three decades can be attributed to the substitution of pastures in the more fertile areas for crops, pushing cattle production toward more marginal areas, and unfavorable events such as the closure of the most profitable export markets because of foot-and-mouth disease.

As illustrated by Figure 14.5, agricultural exports are even more concentrated than output, with shipments of the soybean complex (i.e., soybeans, soybean oil, and soybean meal) accounting for 45% of the total in 2005-07. The next largest share corresponds to exports of the cattle complex (i.e., meat and leather), with 11%, followed by exports of the wheat and corn complexes, with 8% and 7%, respectively. Approximately 75% of the total value of exports stems from the largest five commodity complexes. In the interest of space, graphs illustrating trends for the main agricultural exports are not shown. However, as implied by

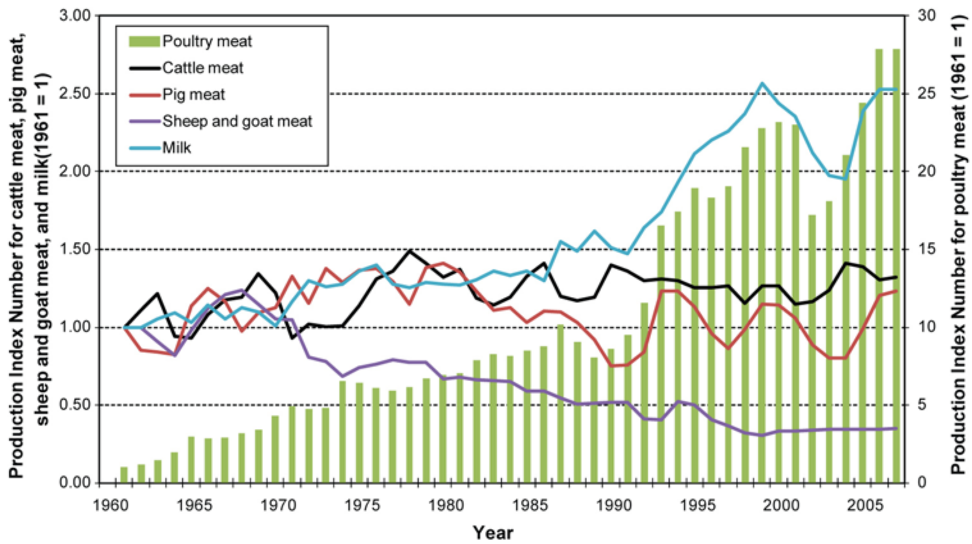

Figure 14.4. Production index numbers for livestock products in Argentina, 1961-2007

Source: Prepared using data from FAOSTAT.

Note: Production indexes are calculated as the quantities produced relative to the year 1961.

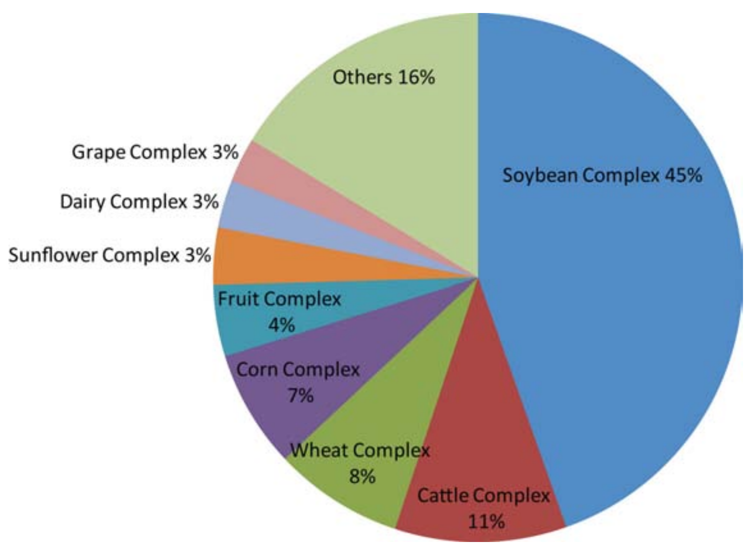

Figure 14.5. Commodity shares of Argentina's total value of exports of agricultural products, 2005-2007

Sources: Prepared using data from Argentina's Instituto Nacional de Estadisticas y Censos (INDEC) and the World Trade Organization.

Note: "Complex" means the primary commodity and its products (e.g., the soybean complex consists of soybean, soybean oil, and soybean meal).

the trends in output values for specific commodities (see Figures 14.3 and 14.4), exports for many individual products have evolved quite differently from aggregate exports over the last four decades.

Argentina is a large country, spanning regions of quite different suitability for agriculture. From a geographical point of view, its agricultural production can be classified into two main categories, namely, output from the Pampean region, and output from the non-Pampean region or "regional economies." The Pampean region comprises the center and East of the country and produces most of the grains, oilseeds, cattle, and milk. The non-Pampean region consists of the rest of the country, and it produces a relatively large range of agricultural goods. These include sheep in the South (Patagonia); grapes and other fruits in the irrigated areas of the West; sugar, citrus, and tobacco leaf in the Northwest; and cotton, tea, and mate (a local herbal drink) in the Northeast. The Pampean region accounts for most of the value of the output and exports of Argentina's agricultural sector. Only one regional product is among the top eight commodities by output value (grapes, with a 3% share), and only two regional commodity complexes are among the top eight exports (fruits and grapes, with 4% and 3% shares, respectively). Pampean agriculture has been the more dynamic of the two regions, as well. Primary agricultural exports from the Pampas and the non-Pampean regions increased by 46% and 29%, respectively, between 2000 and 2004 (World Bank 2006).

A major common denominator of the agricultural products from the non-Pampean region is that they tend to be mostly consumed by the domestic market (Reca 2006). Many of the non-Pampean agricultural products come from perennial plants (e.g., fruits, grapes, tea, and mate), rendering them unresponsive to short-run demand shifts (Reca 2006). Other distinguishing characteristic of agriculture in the Pampas region as compared with the non-Pampean is that the Pampas is generally more intensive in the use of machinery and management, and more extensive in the use of land and labor (Sturzenegger and Salazni 2008). Importantly, unlike most products from the Pampas, large components of the non-Pampean output have traditionally received some form of government protection (Reca 2006).

3. EVOLUTION OF ARGENTINEAN AGRICULTURAL POLICIES SINCE THE 1940S

Argentina enjoys a very favorable natural endowment for agricultural production, consisting of a large area of arable land characterized by temperate climate, adequate rainfall, and in close proximity to ports accessible by grain vessels. This favorable environment has allowed Argentinean agriculture to grow and prosper, even though, starting in the mid-1940s, the sector has suffered from policies aimed at promoting industrial development by transferring resources from the agricultural and rural sectors to the industrial and urban ones (World Bank 2006).

Policies transferring resources from agriculture to the manufacturing sector started to be implemented immediately following World War II. These policies were the result of the difficulties experienced by Argentina's agricultural exporters, and the favorable outlook for manufacturers in the domestic market. Argentina's agricultural exports had first suffered because of the large drop in world agricultural prices that accompanied the Great Depression of the 1930s. Then, piles of unsold grain accumulated during World War II because of restrictions on naval trade during the war. At the same time, the war also made it extremely difficult to import manufactured goods, which greatly improved the outlook for producing such goods to satisfy the needs of the domestic market (Sturzenegger and Salazni 2008).

The polices that began after World War II were aimed at promoting industrial growth by favoring import substitution (i.e., the domestic production of imported manufactures), and using resources from the agricultural sector to support them. The agricultural sector was taxed by means of a combination of export duties, overvalued exchange rates, and public marketing boards (World Bank 2006). In the case of wheat, for example, this translated into a discrimination exceeding 50% (Sturzenegger and Salazni 2008). Sturzenegger (1990) estimated that as of the early 1980s, such policies had transferred over 60% of agricultural GDP to other sectors in the economy. Several studies have shown that these policies had a substantial negative effect on Argentina's agricultural sector. For example, Reca and Parellada (2001) reported that average annual agricultural production over 1950-52 was 20% smaller than over the period 1940-42.

Soon after World War II, a comprehensive set of welfare state policies was also introduced by the Peron administration. This was initially financed with assets that the government had accumulated during the war, which stemmed from the account surplus associated with the lost import opportunities at the time of the armed conflict. As those assets were depleted over time, financing the welfare state became a recurrent problem for the government. According to Sturzenegger and Salazni (2008), this lies at the heart of the chronic fiscal struggle and inflationary pressure that Argentina has faced since then.

In the early 1990s, major policy changes took place that had a substantial impact on the agricultural sector. General policy changes included trade liberalization, deregulation, privatization of many state enterprises, the creation of Mercosur (the Southern Common Market), and, perhaps most important of all, a currency convertibility program (Sturzenegger and Salazni 2008). The currency convertibility program was designed to eliminate the main source of inflationary pressures, that is, the creation of money to finance the public sector deficit. The convertibility program consisted of a currency board that fixed a nominal relation of one peso to one U.S. dollar.

Policy changes directly concerning agriculture involved the abolition of quantitative restrictions and the reduction of tariffs on imports of inputs (e.g., fertilizers, herbicides, machinery, and irrigation equipment), the removal of export taxes, the elimination of commodity boards, the significant reduction of inefficiencies and red tape in the marketing channel (e.g., transportation and ports), and the elimination of tax distortions in fuels (World Bank 2006). As depicted in Figure 14.6, these policy changes triggered substantial increases in the imports of fertilizers, pesticides, and agricultural machinery, which translated into much greater usage of these inputs (see, e.g., Figure 14.7). As a result, the area harvested with the main annual crops expanded by about one-quarter during the 1990s (see Figure 14.8). Not surprisingly, crop production grew at a much faster pace in the 1990s than in previous decades. Livestock production, however, did not show faster growth over this decade (see Figure 14.1).

Unfortunately, the economic crisis experienced by Argentina's main trade partner, Brazil, and record low world agricultural commodity prices combined to negatively affect the Argentinean economy at the end of the 1990s. The peso became increasingly overvalued against the currencies of Argentina's main trade partners (Brazil and the European Union), and problems continued to mount within the economy until it collapsed at the end of 2001, along with the convertibility program scheme. The economic debacle triggered a huge capital outflow, a devaluation in excess of 200%, and a default in external and public debts (Sturzenegger and Salazni 2008). According to data from Argentina's Instituto Nacional de Estadisticas y Censos (INDEC), GDP sunk by more than 10% between 2001 and 2002, and in 2002 unemployment and the percentage of population living below the poverty line exploded to 22% and 54%, respectively, all figures illustrative of the depth of the economic crisis suffered by the country.

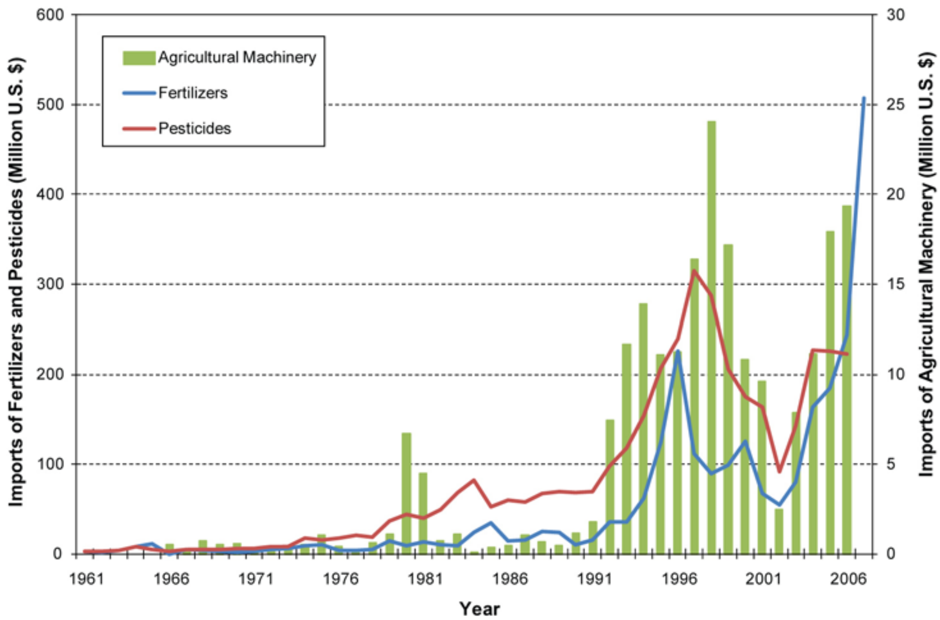

Figure 14.6. Imports of fertilizers, pesticides, and agricultural machinery by Argentina, 1961-2007
Source: Prepared using data from FAOSTAT.

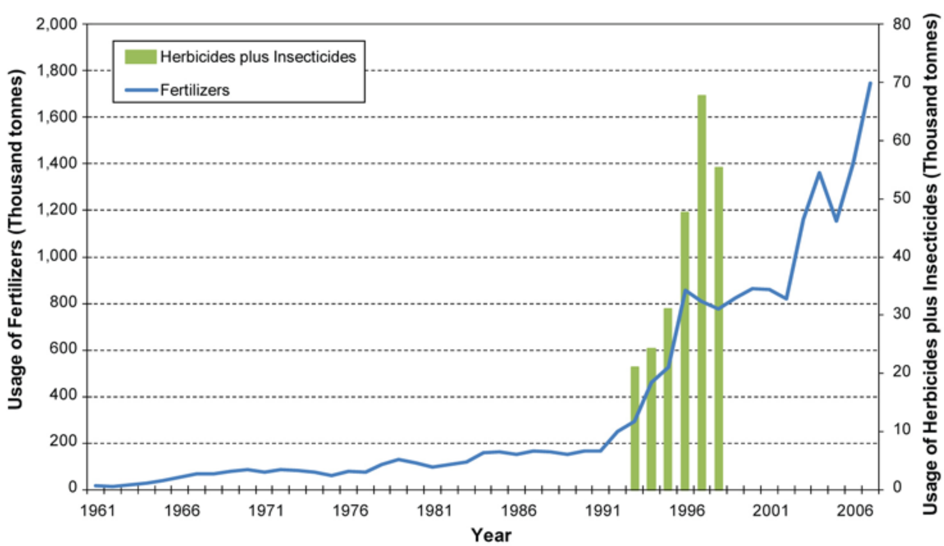

Figure 14.7. Usage of fertilizers and herbicides plus insecticides in Argentina, 1961-2007
Source: Prepared using data from FAOSTAT.
Note: Data for herbicides plus insecticides are not available for 1961-1992 and 1999-2007.

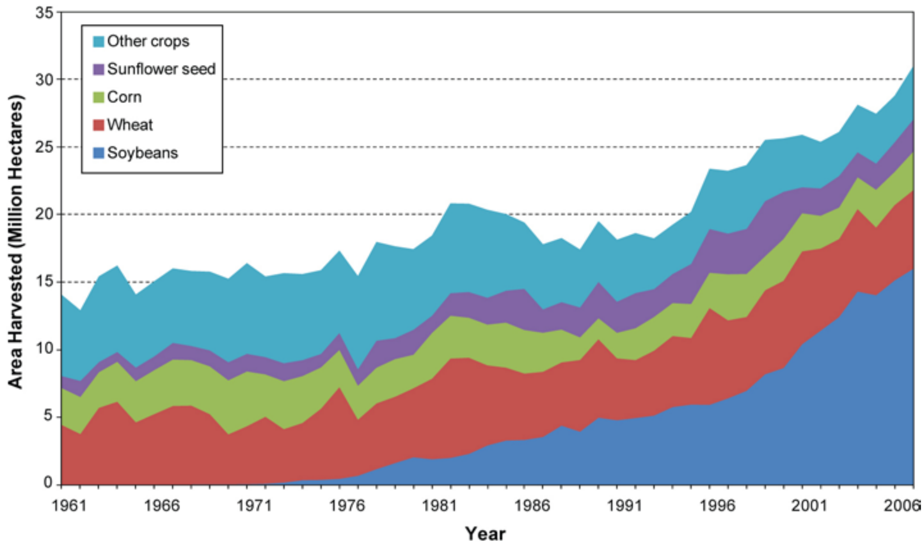

Figure 14.8. Area harvested in Argentina, 1961-2007
Source: Prepared using data from FAOSTAT.

In the few years following the 2001 collapse, the economy experienced a strong recovery, with GDP growing by 41% between 2002 and 2006, employment falling to slightly less than 10% in 2007, and the percentage of population living under the poverty line reduced by almost half in 2006 compared to 2002. The recovery was spurred by the restoration of confidence in the economy, induced by sensible macroeconomic measures such as a restructuring of the public debt, the restoration of a fiscal surplus, and the accumulation of international monetary reserves by the Central Bank. The agricultural sector played a major role in regard to the fiscal surplus and the accumulation of reserves, because the crisis prompted the government to impose taxes on agricultural exports once again to obtain much-needed hard currency. Interestingly, the party in power since the crisis has been the one founded by Peron, who was instrumental in promoting policies that discriminated against agriculture in favor of the domestic manufacturing sector after World War II.

Fortunately, the years following the crisis were characterized by very favorable conditions in the world markets for Argentina's main agricultural products, which allowed a significant expansion of agricultural exports, and with it tax revenues and foreign reserves. Between 2002 and 2005, taxes on exports originating in the agricultural sector averaged 2.2% of GDP, 9.2% of the value of exports, and 9.9% of all tax revenues (Nogues and Porto 2007). Ultimately, however, high international commodity prices led to the current tug-of-war between the Argentinean government and the agricultural sector (Bisang 2008).In the case of staples of the Argentinean diet, high world prices put pressure on the government to avoid increases in their domestic prices. Exports of meat and dairy products, initially taxed at about 15%, were either banned or restricted to meet this goal (Nogues and Porto 2007, IICA 2007 and 2009). For wheat and corn, a complex compensation scheme was instituted so that domestic users could buy these grains at a more favorable price than that available to exporters (Nogues and Porto 2007; IICA 2007 and 2009). In the case of soybeans, which are barely consumed in the domestic market, high world prices induced the government to raise the export taxes to increase fiscal revenues. Export taxes on soybeans were successively raised from 13% to 23.5%, to 27.5% in early 2007, and to 37.5% in mid-2007. At the same time, domestic prices of imported inputs continued to increase following the world markets. In 2008, the government decision to increase soybean export taxes even further to 45% and to make them variable (so that any world price increases would trigger automatic tax increases above 45%) triggered an unprecedented set of farm strikes (Bisang 2008; IICA 2009). Eventually, the variable export tax scheme was defeated in Congress by the narrowest of margins, and the crisis is likely a major reason for the defeat of the Peronist administration in the mid-elections of 2009.

After losing the recent mid-term elections, the present administration has successfully managed to stick to its policies of heavily discriminating against agriculture. However, large losses in the agricultural sector during the past year due to a widespread drought, less favorable world market conditions, and the significant taxes on exports have induced the country's leaders to break with the past and seek political alliances aimed at reversing the traditional policies of taxing agriculture to favor the industrial sector. As of the present writing, it is very difficult to predict the future course of agricultural policies, because it greatly depends upon which of the confronting power groups prevails. If the views of the present administration succeed, it seems clear that agricultural policies in the future will resemble the ones that characterized the period between World War II and 1991. The opposite situation would be more in line with the experience during the 1990s, during which Argentinean agriculture flourished.

3.1. Quantifying the Discrimination Against Agriculture

The discriminating nature of Argentina's policies against agriculture were quantified by two recent studies conducted by Sturzenegger and Salazni (2008) and Sturzenegger (2007). To this end, the authors computed the nominal rate of assistance (NRA) for product j (NRA_j), defined as

$$NRA_j = (RP_j - UP_j)/UP_j. \tag{1}$$

In equation (1), RP_j denotes the (distorted) price received by domestic producers of good j, whereas UP_j represents the respective undistorted price. That is, NRA_j measures the percentage by which the actual price of commodity j differs from its price without government intervention.

Figure 14.9 depicts five-year averages of NRAs for aggregated tradable products from the agricultural and non-agricultural sectors for 1960-65 through 2000-05. The graph nicely illustrates the extent to which Argentinean policies have historically discriminated against agricultural products and in favor of manufactures from the industrial sector. For the period examined, discrimination against agriculture was at its highest in 1960-65, when NRA was -25.3%. This means that, in aggregate, different forms of government intervention effectively reduced prices of agricultural products by one-fourth of the non-distorted level over 1960-61. Discrimination against agriculture gradually declined until 1995-99, when it reached its lowest level, with an NRA of only -4%. Since then, however, discrimination against the sector has increased by a large amount, with NRA averaging -16.2% in 2000-05. Further, the discrimination worsened after the studies were conducted, because of the increase in export tariffs and the imposition of quantity restrictions on exports that took place after 2005.

The bias against agriculture stands in sharp contrast to the support provided to non-agricultural manufactures. In the first half of the 1960s, prices of non-agricultural tradable goods were effectively being subsidized by 61.4%, while agricultural tradable prices were taxed at a rate of 25.3%. The favorable treatment toward the manufacturing sector has continued since then but at diminishing rate. Over the period covered by Sturzenegger and Salazni (2008) and Sturzenegger (2007), support of tradable manufactures was at its lowest in 2000-05, when NRA averaged 5.3%.

To better appreciate the extent to which the agricultural sector is being discriminated against by governmental policies, it is instructive to compare the agricultural NRA values for Argentina and other countries. To this end, Figure 14.10 ranks the countries included in the set of the world's top 20 agricultural producers, or the world's top 20 exporters of agricultural products, or both, according to their average NRA indexes for agriculture over the period 2000-05.

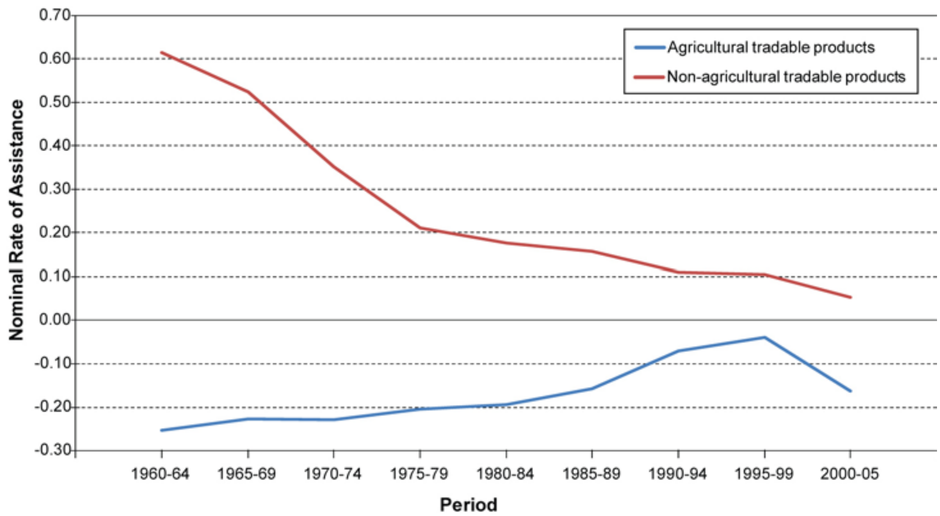

Figure 14.9. Nominal rate of assistance (NRA) for tradable products, five-year averages, 1960-64 through 2000-05
Source: Prepared from data in Table 2.3 in Sturzenegger and Salazni 2008.

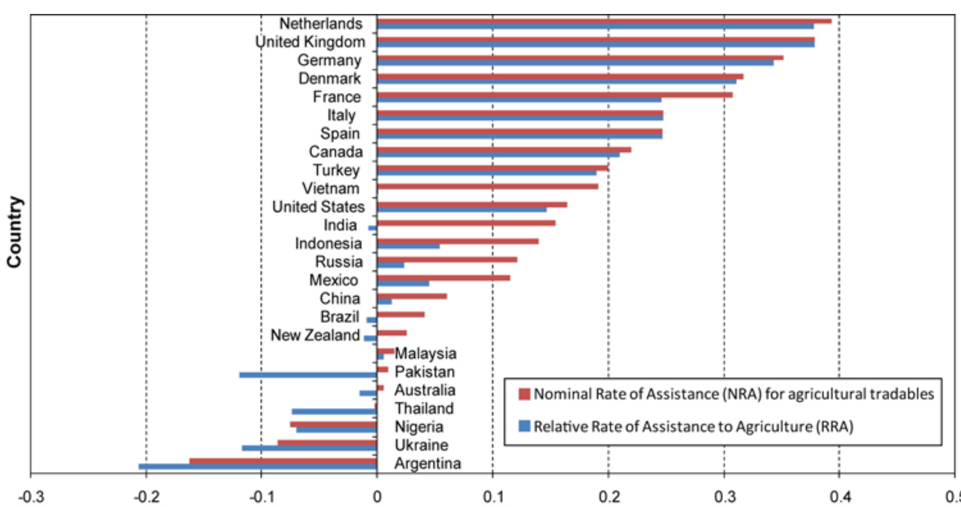

Figure 14.10. Nominal rate of assistance (NRA) for agricultural tradables and relative rate of assistance to agriculture for selected countries, average 2000-05
Source: Prepared with data from Anderson and Valenzuela 2008.
Note: The selected countries are among the top 20 producers of agricultural products or the top 20 agricultural exporters, or both, over 2005-07, according to value of production and trade data reported by FAOSTAT.

Interestingly, only 4 of the 25 countries in the set have negative NRAs, i.e., discriminate against agriculture, and Argentina has the smallest NRA value of them all. Figure 14.10 also displays the relative rate of assistance to agriculture (RRA), which is defined in equation (2):

$$RRA = (1 + NRA_{AgTrad})/(1 + NRA_{NonAgTrad}) - 1, \qquad (2)$$

where NRA_{AgTrad} and $NRA_{NonAgTrad}$ are the NRA aggregate indexes for the country's agricultural tradable products and non-agricultural tradable goods, respectively. Therefore, RRA quantifies the extent to which policies are biased in favor (if positive) or against (if negative) the agricultural sector relative to the non-agricultural sector. By this measure, only 9 of the 25 countries in the selected set shown in the graph had policies biased against agriculture (i.e., had negative RRA values) over the 2000-05 period, and Argentina's policies were clearly the most biased against the sector.

The smoothness of the five-year NRA average for agricultural tradables displayed in Figure 14.9 masks wide annual variations among the NRA indexes for individual commodities. This can be observed in Figure 14.11, which shows the annual NRA values for wheat, corn, soybeans, sunflower, beef, and milk. The

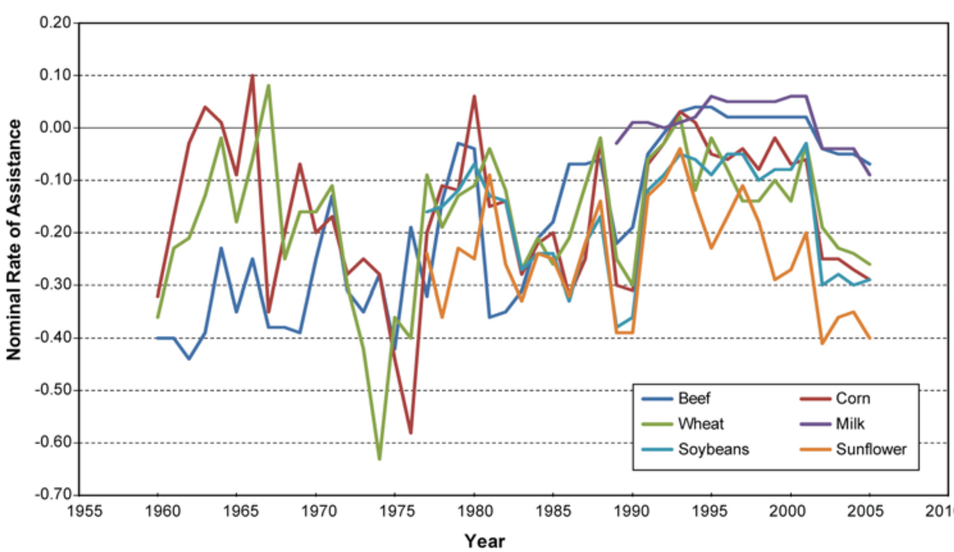

Figure 14.11. Nominal rate of assistance (NRA) for major agricultural products in Argentina, 1960-2005

Source: Prepared from data in Appendix Table B.1 in Sturzenegger and Salazni 2008.

common denominator among the reported NRA series is that, except for a few observations, they are all negative. Based on an econometric analysis of corn, wheat, soybeans, and beef, Sturzenegger (2007) found that their NRAs fall when the world prices for the respective commodities rise, and when the real exchange rate goes up. From this, the author concluded that Argentinean trade policies toward agriculture have had a "compensatory" role; more specifically, they have tended to smooth the time variability in farmland rents. He also found the econometric results consistent with the hypothesis that the level of discrimination against agriculture has been historically determined by a "political market," consisting of representatives from agriculture on one side and representatives from other sectors on the other. At times when profitability for individual agricultural commodities decreased, those in the agricultural sector tended to exert more pressure on the political market to reduce the bias against them. The opposite was true when profitability for agricultural products increased.

4. MAIN DEVELOPMENTS IN ARGENTINEAN PRODUCTION AGRICULTURE SINCE 1990

It is evident from the previous discussion that a major structural change seems to have occurred in Argentinean agriculture in the early 1990s. For example, growth in the value of crop output has been significantly larger after 1990 than over the three preceding decades (see Figure 14.1). Similarly, production of oilseeds underwent a major expansion relative to grain production, and the total area harvested grew at a noticeably faster pace after 1991 (see Figures 14.3 and 14.8). At the same time, annual usage of fertilizers and pesticides greatly exceeded the amounts used in any year prior to 1990 (see Figure 14.7). Several developments took place in Argentinean production agriculture that contributed to the increased growth rate in crop value observed after the early 1990s. The most important ones, however, were (a) the modernization of the technologies used by agricultural producers, (b) the expansion of the crop frontier, (c) the greater intensity in the usage of farmland in the Pampean region, and (d) the advent of "planting pools." In the case of beef production, the most noteworthy development has been the explosive growth of feedlots over the last decade. These developments are discussed next.

4.1. Technological Modernization

After the 1990s, Argentina's agricultural sector underwent a significant technological modernization. Trade liberalization in the 1990s favored imports of less expensive and more efficient machinery for agriculture (see Figure 14.6). Liberalization also allowed local producers of agricultural machinery to buy foreign inputs, greatly reducing their costs and improving the quality of their products (Chudnovsky and Lopez 2005). Greater usage of fertilizers and agrochemicals was spurred by the liberalization of trade and the increase in the local capacity to produce these inputs (see Figure 14.7) (Chudnovsky and Lopez 2005). Storage capacity in permanent facilities more than doubled after the late 1980s, from 32 million tons in 1987, to 56 million tons in 2000, to 70 million tons in 2007 (Lopez and Oliverio 2008). The late 1990s also witnessed the introduction and widespread adoption of disposable storage bags, which greatly expanded storage capacity and provided crop producers with much greater flexibility in the commercialization of their crops. It is estimated that storage bags accounted for 30% of Argentina's grain storage capacity as of 2007 (Lopez and Oliverio 2008).

Another major technological change was the introduction of genetically modified (GM) organisms in the mid-1990s, such as glyphosate-resistant soybeans and Bt corn. In 1996, glyphosate-resistant soybeans became the first transgenic crop commercially released in Argentina (Trigo and Cap 2006). As evident from Figure 14.12, glyphosate-resistant soybeans proved to be hugely popular among producers, who increased the area planted with it from an almost negligible amount in 1996 to essentially 100% after 2004. GM corn was also rapidly accepted by Argentinean producers, with an adoption rate of 20% in 2000 and stabilizing at about 70% after 2003. The adoption rate for GM cotton, on the other hand, was low for several years, but it exploded to over 90% in 2006. Notably, Argentina has consistently ranked second in the world (after the United States) in terms of area planted with GM crops.

Linked to both the modernization of machinery and the widespread adoption of glyphosate-resistant soybeans is the incorporation of zero-tillage technology. According to Ekboir and Parellada (2002), zero tillage constitutes the most significant agricultural technology introduced in Argentina over the last 50 years. Zero tillage consists of planting crops in soil without previous tillage, by opening only a slot in the soil with the smallest dimensions consistent with the appropriate coverage for the desired seeds. Testing of the zero tillage technology started in the 1970s, but it became widely adopted in the late 1990s. In 2001, it was estimated that 7.3 million hectares were planted using zero tillage in Argentina, or one-third of the area planted with annual crops at the time (Cetrangolo

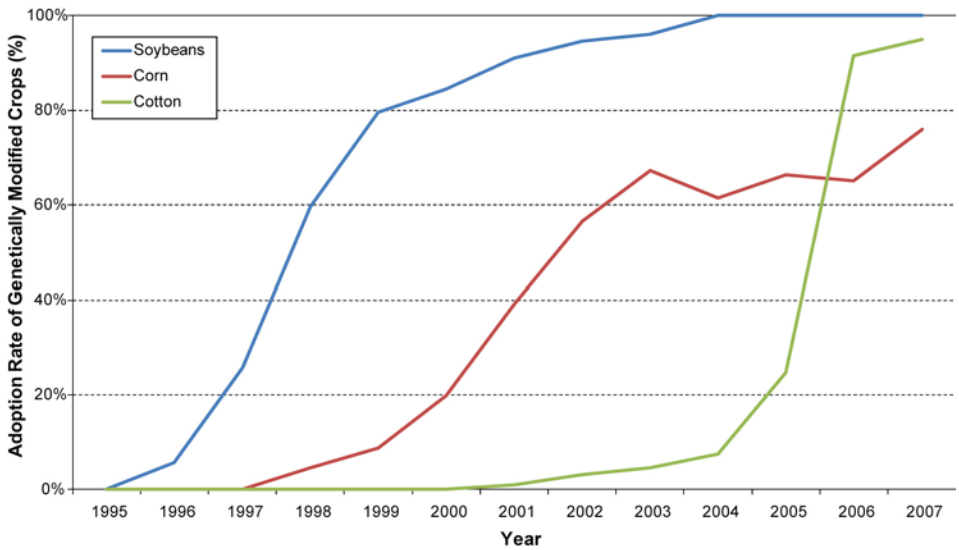

Figure 14.12. Adoption rates of genetically modified crops in Argentina, 1996-2007
Sources: Prepared using data from Trigo and Cap 2006; James 2006, 2007; and FAOSTAT.

et al. 2007). A critical factor underlying the widespread adoption of zero tillage in Argentina was the introduction of glyphosate-resistant soybeans, because glyphosate resistance allows for a very thorough and cost-effective weed control. The soybean crop uses zero tillage most prevalently, with 75% of first-crop soybean area and 83% of the second-crop soybean area planted with this technology in 2007 (SAGPyA). In 2007, adoption rates of zero tillage for the other major crops were 74% for corn, 72% for wheat, and 45% for sunflower (SAGPyA).

Zero tillage has contributed to the expansion of agricultural production in several ways. First, it has significantly reduced production costs. Zero tillage requires costly and specialized planting machines, but it eliminates the need to till the soil and perform other types of work associated with conventional crop production technologies. Second, zero tillage has allowed planting in areas poorly suited to conventional crop production methods, contributing to the expansion of the crop frontier and the more intensive use of land (see Section 4.2). Third, by reducing the deterioration of land caused by conventional tillage, zero tillage has permitted the conversion of some land from crop-pasture rotations to permanent agriculture. Under traditional tillage, rotations with pastures were required to restore soil structure and fertility after several years of cropping. In contrast, well-managed zero tillage (i.e., using appropriate rotations of low-stubble crops such as soybeans and high-stubble crops such as wheat and corn) can preserve soil resources. Finally, zero tillage has also greatly facilitated the planting of soybeans immediately following the wheat harvest, resulting in two crops in the same year.

4.2. Expansion of the Crop Frontier

As illustrated in Figure 14.13, the area planted with crops in the non-Pampean regions remained relatively stable at slightly over four million hectares until the mid-1990s, but it has essentially doubled since then. The main expansion took place in the Northeast and Northwest regions where soybeans were planted. According to the national census, between 1988 and 2002 the planted area in those two regions jumped from 2.5 to 4.3 million hectares. This means that the Northeast and Northwest increased their share of Argentina's total area with crops from 13.7% in 1988 to 17% in 2002. A key factor underlying this expansion was the aforementioned introduction of zero tillage, which made it possible to grow crops profitably in areas too marginal for conventional planting technologies.

4.3. More Intensive Land Usage in the Pampean Region

The area planted with annual crops in the Pampas grew by about 50% between the early 1990s and 2007, from slightly over 15 million hectares to around 23 million hectares (see Figure 14.13). Land usage in the Pampean region became more intensive by increasing the area planted with crops relative to permanent pastures, and by relying more heavily on double-cropping. In a substantial proportion of the area, the traditional scheme of rotating crops with permanent pastures, used to restore soil structure and fertility, was changed, either by shortening the cycle with pastures or by eliminating it altogether and switching to continuous cropping. At the same time, double cropping wheat and soybeans (and, to a much smaller extent, barley and soybeans) became a very popular choice for agricultural producers in the Pampas. Between 1996 and 2007 the area planted with soybeans as a second crop is estimated to have increased by about 130%, from 1.9 to 4.4 million hectares (see Figure 14.14). As noted earlier, a major contributor to the popularity of second-cropping was the introduction of zero tillage together with glyphosate-resistant soybeans and glyphosate. The glyphosate technology package preserves soil moisture, saves planting time at a critical period, and greatly facilitates weed control.

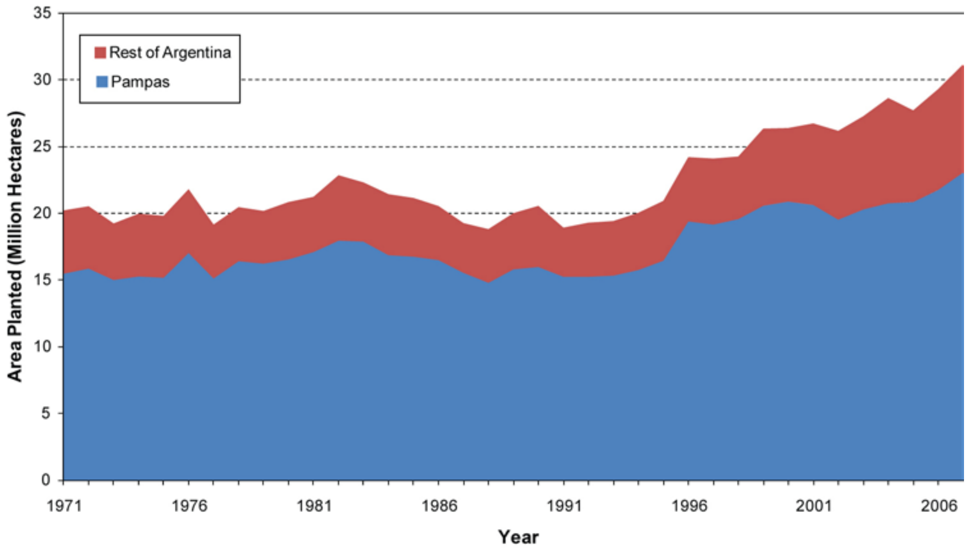

Figure 14.13. Area planted with cereals and oilseeds in the Pampas and the rest of Argentina, 1971-2007
Source: Prepared using data from SAGPyA.
Note: "Pampas" is being approximated here by the provinces of Buenos Aires, Santa Fe, and Cordoba.

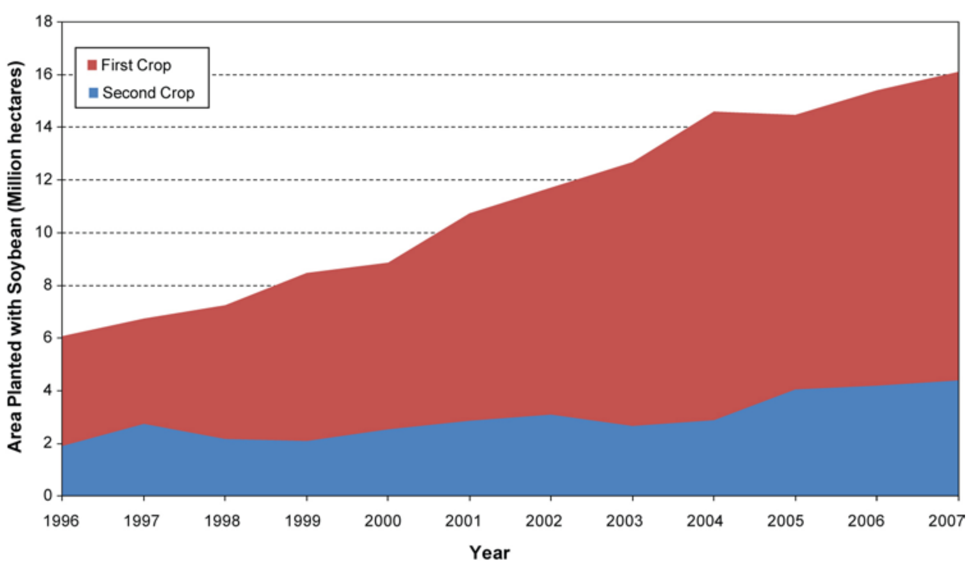

Figure 14.14. Area planted with soybeans as first and second crop in Argentina, 1996-2007
Sources: Prepared using data from Trigo and Cap 2006 and SAGPyA.

4.4. Planting Pools

In the mid-1990s, a new organizational form of production agriculture appeared in Argentina, namely, the "planting pool." Planting pools consist of agreements among producers and other agents that provide for various factors that enter the production and/or commercialization process (e.g., in-kind inputs, labor, and financing). Arrangements may vary greatly, including some in which the producer keeps managing the farm and the planting pools provide for technical assistance, financing, and risk diversification. In other instances, the pools rent vast tracts of farmland, which allows them to exploit economies of scale and benefit from the geographic diversification of risks. Some pools have even expanded to farm land in neighboring countries (e.g., Paraguay, Uruguay, Bolivia, and Brazil). As of 2002, over 50% of operations involved mainly in crop production farmed third-party farmland under various contractual arrangements. Planting pools are now quite common in Pampean agriculture (World Bank 2006).

Planting pools have contributed to the expansion of agricultural output in Argentina in various ways. First, they are a major source of financing for agricultural production. Some studies argue that the perennial lack of adequate financing in Argentinean agriculture was a major reason for the advent of planting pools (World Bank 2006). In recent years, planting pools captured funds from both short- and long-term investors outside of agriculture. Some of the largest pools have also successfully issued equity shares aimed at attracting capital from foreign investors. Second, planting pools tend to incorporate better production practices and more advanced technology. Data from the 2002 agricultural census shows that planting pools are more likely to perform soil analysis and monitor pests. Finally, planting pools tend to use more effective tools to manage risks (e.g., insurance, hedging, and geographic diversification), which provides them with an edge over more traditional forms of organizing agricultural production (World Bank 2006). Overall, planting pools have greatly contributed to the separation of land ownership from the management of agricultural production (Bisang 2008).

4.5. Beef Production Using Feedlots

In recent years, the most noticeable development in the livestock sector has been the widespread use of feedlots to produce beef. Traditionally, Argentinean cattle were raised on pastures. However, the strong trend toward the replacement of pastures by crops, which accelerated after 1990, motivated the adoption of feedlots as a way to produce beef using less land. Because the best-suited lands for crops are in the Pampas, a relative relocation of cattle from the Pampas to the non-Pampean regions took place along with this shift in farmland usage. The share of the cattle stocks in the Pampas fell from 62% in 1994 to 58% in 2003, and fell further to 50% in 2008 (Canosa, Iriarte, and Tonelli 2009). Together with better management of pastures and technology (e.g., fertilization and genetics), production of beef in feedlots is one reason why meat production has remained at relatively stable levels despite the reductions in pasture area and the total stock of cattle (see Figures 14.4 and 14.15) (Canosa, Iriarte, and Tonelli 2009).

Initially, feedlots were used seasonally as a means to counteract the seasonal drops in the supply of forage from natural pastures. Over time, however, feedlots have tended to become year-round operations, with substantially more uniform and higher-capacity utilization rates. In 2008, capacity utilization for the feedlot industry reached record levels, with no month falling under a rate of 70% (Camara Argentina de Feedlots 2009). In addition to the switch in land use from pastures to crops, there are two factors that have contributed to the increased popularity of feedlots, one of them driven by demand and the other related to supply. On the demand side, stricter requirements by domestic buyers, in terms of both meat quality and uniformity, have clearly favored animals fattened in feedlots over traditional grazing-based beef. On the supply side, a scheme of government reimbursements

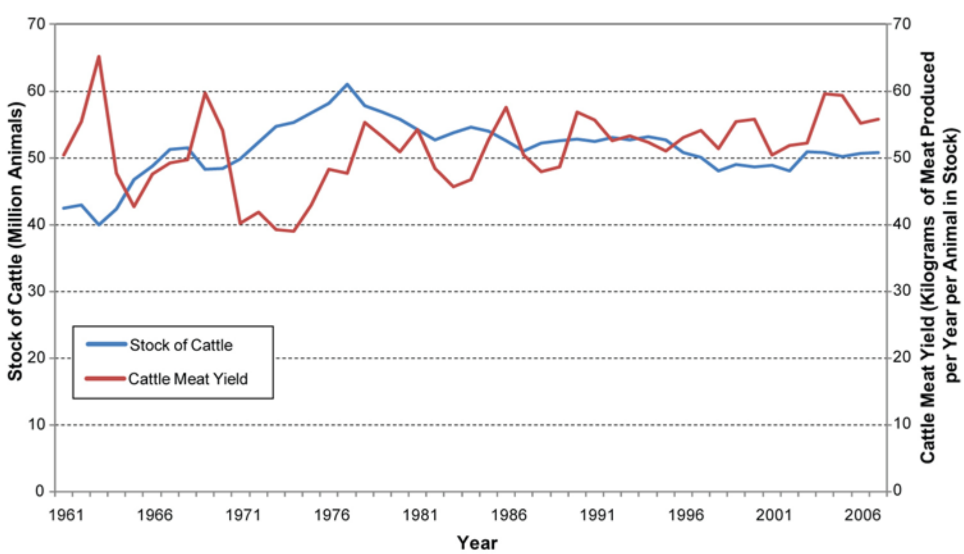

Figure 14.15. Stock of cattle and cattle meat yield in Argentina, 1961-2007
Source: Prepared using data from FAOSTAT.

to feedlots instituted in early 2007, by which registered operations are offered partial refunds for the cost of grains used for feeding cattle in feedlots, has been instrumental in the recent further surge in feedlot production.

According to official statistics, in September 2008 there were 1,400 registered feedlots, which produced 3.6 million animals in the previous year, or about 30% of the total amount of fat cattle slaughtered in Argentina in that year. However, these figures underestimate the actual incidence of feedlots, as many of the operations are not officially registered. It is estimated that slaughter of cattle produced in feedlots increased from 1.5 million animals in 2001 to between 4.5 and 5 million animals in 2009. Nowadays, feedlots consume almost one-fifth of the total corn output produced by Argentina (Camara Argentina de Feedlots 2009).

5. PARTIAL PRODUCTIVITY TRENDS

As pointed out earlier in connection with Figures 14.1 and 14.3, crop production in Argentina has consistently increased since 1960, and its growth seems to have accelerated after the early 1990s. Over the same period, land planted with crops also went up, particularly since the early 1990s (see Figure 14.8). Overall, however, growth in crop production outpaced the increase in land utilization, resulting in positive trends in the yields of all of the major crops (see Figure 14.16). Corn had the largest yield increase, as its output per hect-

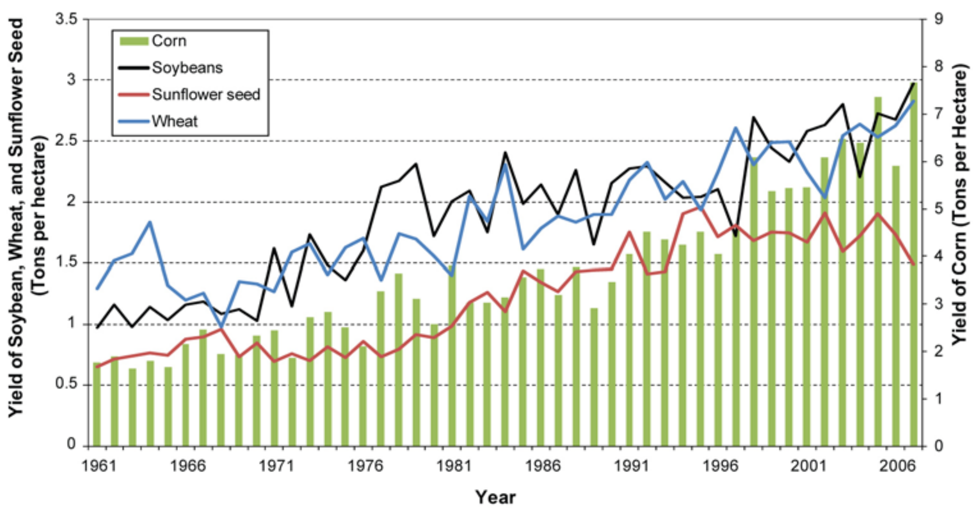

Figure 14.16. Yield per hectare of soybeans, corn, wheat, and sunflower seed in Argentina, 1961-2007
Source: Prepared using data from FAOSTAT.

are almost quadrupled, from 1.8 tons in 1961-63 to 7.0 tons in 2005-07. Next was soybeans, whose yield rose from 1.0 ton per hectare in 1961-63 to 2.8 tons per hectare in 2005-07, for a gain of over 150%. The yield of sunflower seed improved until the mid-1990s, with output per hectare more than doubling between 1961-63 (0.7 tons) and 1994-96 (1.7 tons). However, sunflower seed yield stagnated afterward. Finally, wheat yield increased by about 80%, from 1.5 to 2.7 tons per hectare between 1961-63 and 2005-07. Overall, the positive trend in crop yields can be traced back to the use of better genetic materials, greater use of inputs such as fertilizer and pesticides (more to follow), and better technologies. Among the technologies, worthy of mention is the technological package involving zero tillage, glyphosate-resistant soybeans, and glyphosate. The increase in average crop yields is even more impressive considering that it took place at the same time that vast areas of more marginal lands were being incorporated into crop production.

As shown in Figure 14.6, usage of fertilizers and pesticides rose substantially beginning in the 1960s, and particularly so after the early 1990s. Unfortunately, partial productivity measures by crop for either input cannot be calculated because data about usage of pesticides by individual crops are not available. However, for crops as a whole, it is clear from Figures 14.1 and 14.6 that productivity of both fertilizers and pesticides fell over the period under analysis, because use of both inputs has grown at a significantly faster pace than crop output.

The evolution of labor and machinery inputs in Argentinean agriculture is depicted in Figure 14.17. As with fertilizers and herbicides, there are no disaggregated series for labor or machinery by agricultural activity. Overall, however, the decline in the number of people employed in the sector indicates that labor productivity improved over the period analyzed. The picture is mixed for machinery inputs as represented by the number of tractors, because this number increased until the late 1980s but fell at a small but steady rate afterward (see Figure 14.17). Although no better series for machinery inputs is available, it is important to note that using the number of tractors to measure machinery inputs has severe limitations. For example, the number of tractors does not take into account the increase in the average power of individual tractors that has taken place since the 1960s. In addition, the adoption of zero tillage has greatly reduced the number of operations needed to grow crops. For these reasons, it seems premature to reach strong conclusions regarding the partial productivity of machinery.

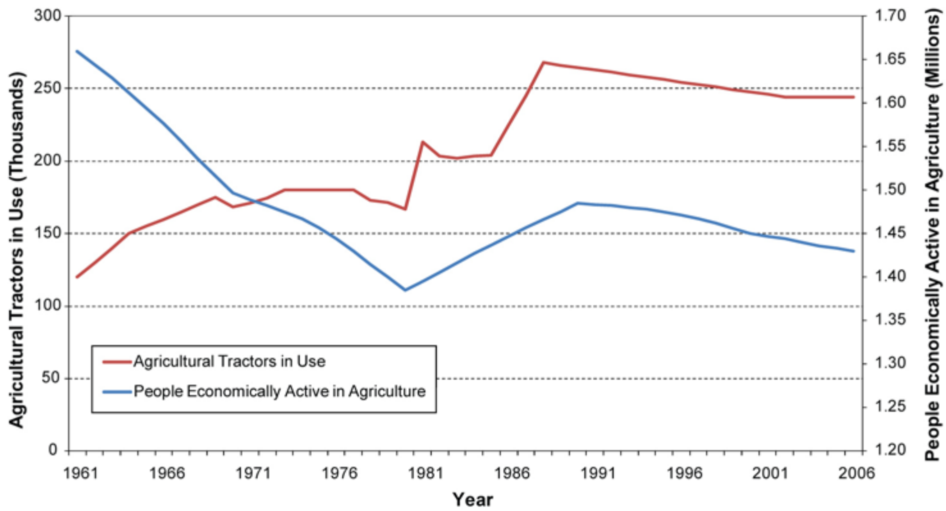

Figure 14.17. Number of people economically active in agriculture and agricultural tractors in use in Argentina, 1961-2007
Source: Prepared using data from FAOSTAT.

In the case of beef production, land productivity increased in recent decades, because total output remained relatively unchanged (see Figure 14.4) while the area devoted to pastures shrunk by a significant amount. Cattle stocks fell by about 10 million animals from the late 1970s, to around 50 million head in 2007 (see Figure 14.15). However, total production of meat remained relatively stable because the fall in stocks was offset by the upward trend in meat yield per animal in stock (see Figures 14.4 and 14.15). The improvement in the productivity of the cattle stock can be attributed to the use of better genetics, better usage of pastures, and improved overall management (Canosa, Iriarte, and Tonelli 2009). Importantly, productivity improved despite the fact that the substitution of crops for pastures displaced cattle stocks toward more marginal areas. More recently, the adoption of feedlots by a significant proportion of finishing operations has contributed to the rise in productivity.

Figure 14.4 shows that milk output increased by about 50% in the three decades following 1960, and then it experienced an explosive and uninterrupted growth of 75% in the 1990s. Milk production fell by more than a quarter between 1999 and 2004, but it improved after that, reaching the peak it had achieved a decade earlier. Between 1960 and the mid-1980s, the productivity of the dairy cattle was essentially flat at about 1.9 tons of milk per year per cow in stock (see Figure 14.18). In the following two decades, however, it increased by more than 150%,

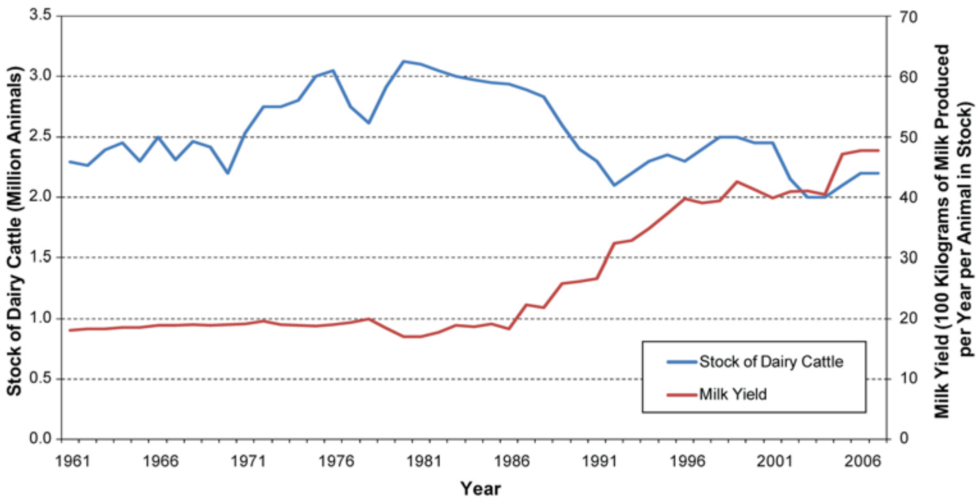

Figure 14.18. Stock of dairy cattle and milk yield in Argentina, 1961-2007
Source: Prepared using data from FAOSTAT.

to 4.8 tons of milk per year per cow in stock. The main factors underlying the advances in productivity are better animal genetics, technology (e.g., artificial insemination and more advanced milking machines), and management (e.g., fertilization and rotation of pastures, and better genetic materials for pastures).

5.1. Some International Comparisons

Figures 14.19 and 14.20 are drawn to compare the productivity of cropland and animal stocks, respectively, for Argentina and other relevant countries. The countries chosen for this purpose are the United States, overall the largest producer and exporter of the main crops and livestock produced by Argentina, and the other top five exporters of each commodity.

Soybean yield in Argentina compares well with the soybean yield that characterizes the country's main competitors in world markets, because it is almost the same as in the United States and more than 20% higher than the average for the other top five exporters. Further, soybean yield in each of the other top countries is below Argentina's. For corn, yield in Argentina is about one-quarter smaller than in the United States. It is important to note, however, that the United States has the highest corn yield among the world's largest corn exporters. Relative to the average of the top five corn exporters, Argentina's corn yield is about 20% larger. Wheat yield is about the same in Argentina as in the United States, but it is one-third smaller than the average

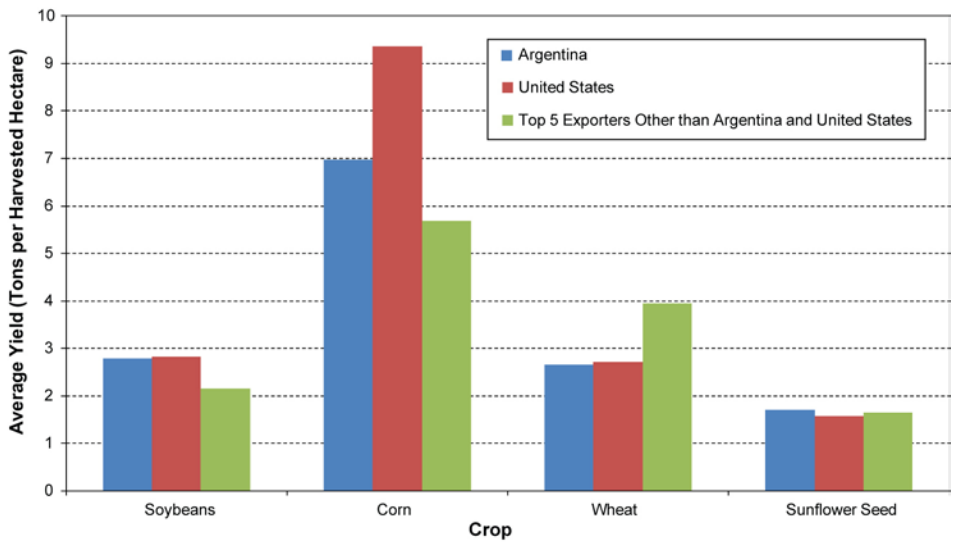

Figure 14.19. Average yield per harvested acre for Argentina and selected countries, 2005-2007
Source: Prepared using data from FAOSTAT.
Note: The top five exporters other than Argentina and the United States are (a) Brazil, Paraguay, Canada, Uruguay, and China for soybeans; (b) France, China, Brazil, Hungary, and the Ukraine for corn; (c) Canada, France, Australia, the Russian Federation, and Germany for wheat; and (d) France, Bulgaria, Hungary, Romania, and the Russian Federation for sunflower seed.

for the other top five wheat exporters. Most noticeably, there is a very large gap between wheat yields in Argentina (2.7 tons per hectare) and in Germany (7.2 tons per hectare), the country with the highest yield from among the other top exporters. Finally, yield of sunflower seed in Argentina is 1.7 tons per hectare, or almost 10% higher than in the United States and about the same as the average for the other top five exporters. In terms of sunflower seed yield among the world's largest exporters, Argentina ranks third behind France and Hungary, but these two countries have significantly larger yields (2.4 and 2.1 tons per hectare, respectively).

According to the graphs displayed in Figure 14.20, Argentina clearly lags its main competitors in terms of livestock productivity. Argentina's meat production per animal in stock is less than half relative to the United States, and almost one-fourth less than the average of the other top five exporters. Among top exporters, only Brazil has lower productivity of cattle stocks than Argentina. The situation is similar regarding the productivity of Argentina's dairy cattle compared to that of the United States and the other top five exporters. In this instance, New Zea-

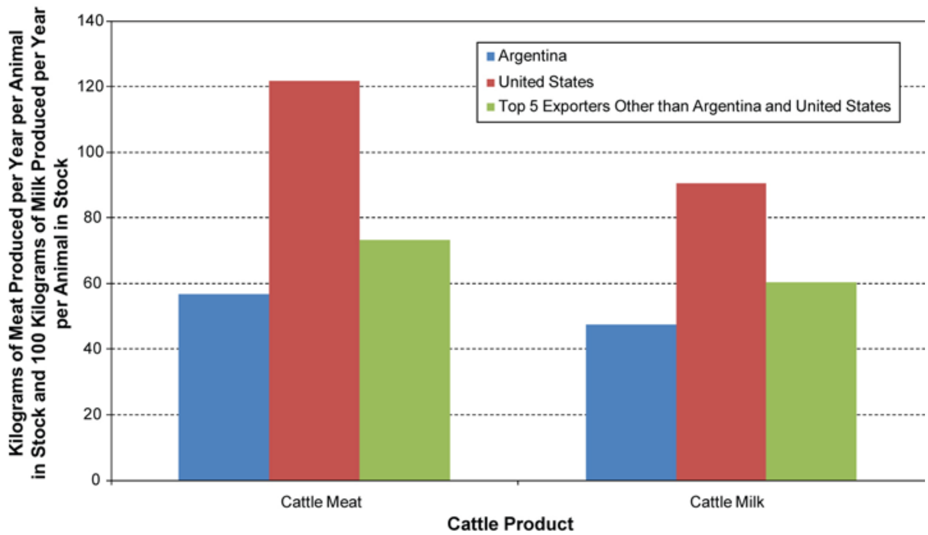

Figure 14.20. Average yield of cattle meat and milk per animal in stock for Argentina and selected countries, 2005-2007
Source: Prepared using data from FAOSTAT.
Note: The top five exporters other than Argentina and the United States are (a) Brazil, Australia, Ireland, New Zealand, and the Netherlands for cattle meat; and (b) Germany, France, the Netherlands, New Zealand and Belgium for cattle milk.

land is the only country among the major milk exporters whose productivity is below Argentina's.

6. TRENDS IN TOTAL FACTOR PRODUCTIVITY

The previous section addressed partial productivity measures for the agricultural sector in Argentina. They quantify the effect on output of individual factors of production, without controlling for the usage of other factors of production. To analyze the productivity of the entire set of inputs entering agricultural production, it is necessary to look at total factor productivity (TFP) measures. This section focuses on TFP measures for Argentinean agriculture.

Outputs and inputs can be aggregated following different methods, leading to alternative ways to measure TFP. Following Coelli, Rao, and Battese (1998), such methods can be classified into four categories: (a) econometric estimation of models based on production functions, (b) accounting relationships, (c) data envelopment analysis (DEA), and (d) stochastic frontiers. Each method has its own advantages and disadvantages, based on the data requirements for estimation, underlying assumptions, and purpose of the analysis. For example, to estimate TFP growth at the country level, the first method assumes that the country production is technically efficient, and it only requires a sufficiently long time series of data for the country. The second method assumes that payments to all inputs are equal to the total value of production but can be estimated with as little data as observations at two distinct points in time. The third and fourth methods allow for technically inefficient production but require data on a cross-section of countries.

Table 14.3 summarizes the results of the eight studies that were performed over the last decade and reported TFP growth measures for the Argentinean agricultural sector for a period ending in 1997 or later. Of these studies, three were based on the estimation of production functions (Artana, Cristini, and Pantano 2001; Bravo-Ortega and Lederman 2004; and Lanteri 2005), two used accounting relationships (Lema 1999; and Dias Avila and Evenson 2004), two relied on DEA (Coelli and Rao 2005; and Nin and Yu 2008), and one estimated a translog stochastic frontier production function (Bharati and Fulginiti 2007). The studies also differed in the data sources used, as three of them employed mainly data from government agencies in Argentina (Lema 1999; Artana, Cristini, and Pantano 2001; and Lanteri 2005), whereas the other five used FAO's database (Bravo-Ortega and Lederman 2004; Dias Avila and Evenson 2004; Coelli and Rao 2005; Bharati and Fulginiti 2007; and Nin and Yu 2008). In this regard, it must be noted that FAO's database allows estimation of TFP for Argentina only up to 2003, because some of the input data series are missing for 2004 and later years.

The numbers shown in Table 14.3 reveal large differences in the TFP growth estimates, as these range from a low indicating an average TFP contraction of 2.7% per year over the period 1980-2000 (obtained by Coelli and Rao 2005) to a high postulating an average TFP growth of 2.88% per year over 1964-2003 (reported by Nin and Yu 2008). The wide range of the reported estimates is noticeable. The earlier discussion about the significant changes that Argentina's agricultural sector experienced after the early 1990s would suggest that such changes may have rendered TFP more difficult to measure with reasonable precision, thus explaining the lack of consensus across TFP estimates. However, the literature indicates that this is not the case, as earlier studies show contradictory results regarding TFP growth for Argentinean agriculture over previous periods. For example, Lanteri (1994) estimated that TFP grew at an average annual rate of 1.9% between 1964 and 1992, and Elías (1992) reported average annual TFP growth rates of 0.49% and 1.09% over the decades 1960-1970 and 1970-1980, respectively. In contrast, according to Arnade (1998), agricultural TFP in Ar-

Table 14.3. Summary of total factor productivity (TFP) growth rates for Argentinean agriculture estimated by recent studies

Study	Period Analyzed	Annual TFP Growth (%)	Method Used	Data Type (Source)
Lema 1999	1970-1997	1.55	Accounting relationship	Time series (SAGPyA)
Artana, Cristini, and Pantano 2001	1981-1999	2.2	Estimated production function	Time series (SAGPyA, INDEC)
Dias Avila and Evenson 2004	1961-1980	1.83	Accounting relationship	Time series (FAOSTAT)
Dias Avila and Evenson 2004	1981-2001	2.53	Accounting relationship	Time series (FAOSTAT)
Bravo-Ortega and Lederman 2004	1961-2000	1.84	Estimated translog production function	Panel of 77 countries (FAOSTAT)
Coelli and Rao 2005	1980-2000	-2.7	Malmquist TFP index from DEA analysis with constrained shadow prices	Panel of 93 countries (FAOSTAT)
Coelli and Rao 2005	1980-2000	0.4	Tornqvist TFP index from DEA analysis with constrained shadow prices	Panel of 93 countries (FAOSTAT)
Lanteri 2005	1955-2003	-0.941	State-space Hicks-neutral estimation of translog cost function	Time series (SAGPyA, INDEC, FAOSTAT)
Bharati and Fulginiti 2007	1972-2002	2.15	Estimated stochastic translog production frontier	Panel of 10 Mercosur countries (FAOSTAT)
Bharati and Fulginiti 2007	1972-1981	3.47	Estimated stochastic translog production frontier	Panel of 10 Mercosur countries (FAOSTAT)
Bharati and Fulginiti 2007	1982-1991	1.38	Estimated stochastic translog production frontier	Panel of 10 Mercosur countries (FAOSTAT)

Table 14.3. Continued

Study	Period Analyzed	Annual TFP Growth (%)	Method Used	Data Type (Source)
Bharati and Fulginiti 2007	1992-2002	2.39	Estimated stochastic translog production frontier	Panel of 10 Mercosur countries (FAOSTAT)
Nin and Yu 2008	1964-2003	2.88	Malmquist TFP index from DEA analysis with constrained shadow prices	Panel of 72 countries (FAOSTAT)
Nin and Yu 2008	1964-2003	2.30	Malmquist TFP index from DEA analysis with unconstrained shadow prices	Panel of 72 countries (FAOSTAT)
Nin and Yu 2008	1984-2003	1.97	Malmquist TFP index from DEA analysis with constrained shadow prices	Panel of 72 countries (FAOSTAT)

gentina contracted at an average annual rate of 1.85% from 1961 through 1993. Trueblood and Coggins (2002) also estimated a contraction in TFP over a similar period (1961-1991), although at a greater average annual rate (2.63%), and Fulginiti and Perrin (1997) found an even greater annual rate of TFP contraction (4.8%) between 1961 and 1985.

Closer inspection of the estimates reported in Table 14.3 reveals additional inconsistencies and/or problems with the recent estimates of TFP growth for Argentinean agriculture. First, the estimates from Nin and Yu (2008) imply that TFP grew at a slower pace over 1984-2003 than over 1964-1983. This is true because the authors estimated an average annual growth rate of 1.97% for the first period, compared to an average annual growth rate of 2.88% over the entire 1964-2003 period. In contrast, using data from the same source (FAOSTAT), Dias Avila and Evenson (2004) found higher TFP growth over 1981-2001 (with an average of 2.35% per year) than over 1961-1980 (with an average of 1.83% per year).

Second, Coelli and Rao (2005) calculated an average annual TFP contraction of 2.7% over 1980-2000, whereas Nin and Yu (2008) estimated that TFP grew at an average annual rate of 1.97% over 1984-2003. These contradictory results are puzzling because the periods they cover largely overlap, they are both based on a very large cross-section of countries from FAOSTAT, and their estimates are both based on calculating a Malmquist TFP index from DEA. The fact that Coelli and Rao (2005) left shadow prices unconstrained for the estimation and Nin and Yu (2008) constrained them doesn't seem to explain the stark difference between their results, as Nin and Yu (2008) show that imposing such a constraint only reduces the average annual TFP growth from 2.88% to 2.30% over the period 1964-2003.

Third, the studies that simultaneously estimate TFP growth for Argentina and other countries show substantially different rankings for Argentina. For example, Argentina's TFP growth ranked 89th among the 93 countries examined by Coelli and Rao (2005), whereas it ranked either second (when shadow prices are constrained) or fourth (with unconstrained shadow prices) among the 73 countries analyzed by Nin and Yu (2008). According to Dias Avila and Evenson (2004), Argentina's agricultural TFP growth ranked 25th and 20th among 78 countries of Latin America, Asia, and Africa over the periods 1961-1980 and 1981-2000, respectively.

Fourth, some of the assumptions adopted for estimation purposes seem to have a major impact on the calculated rates of TFP growth. For example, Coelli and Rao (2005) showed that by using a Tornqvist TFP index instead of a Malmquist TFP index, the estimated average change in TFP increases from a contraction of 2.7% per year to a growth of 0.4% per year. Less dramatic but nonetheless substantial is the impact of relaxing the assumption of Hicks-neutral TFP changes, reported by Lanteri (2005). Lanteri found an average annual TFP contraction of 0.941% over 1955-2003 when imposing Hicks neutrality, compared to virtually no TFP change on average (i.e., an annual contraction of 0.005%) over the same period when allowing for Hicks non-neutrality.

Fifth, the estimation method may have a major impact on TFP growth estimates. Evidence of this is that using DEA, Fulginiti and Perrin (1997) estimated that TFP contracted at an average annual rate of 4.8% between 1961 and 1985. In contrast, employing a stochastic frontier approach, Bharati and Fulginiti (2007) found that TFP grew at averages of 3.47% per year from 1972 through 1981 and 1.38% per year from 1982 through 1991. An implausibly large contraction in TFP over the decade 1961-1971 would be required for the results from the two studies to be consistent with each other.

In summary, the results reported in Table 14.3 strongly indicate that existing estimates of TFP growth for agriculture in Argentina are quite imprecise. Exploring the reasons for this state of affairs is beyond the scope of the present study, but suffice it to say that likely potential culprits include poor quality of data and unwarranted theoretical assumptions regarding the theoretical models used to fit the data. Regarding data quality, it must be noted that, for example, none of the input series employed by the cited studies is adjusted for quality (e.g., one unit of land in sub-Saharan Africa is assumed to be the same as one unit of land in Argentina). Also, as noted in connection with Figure 14.17, FAOSTAT's number of agricultural tractor series seems a very poor approximation for the usage of agricultural machinery. As per the theoretical assumptions, for example, DEA assumes that unexplained residuals are entirely attributable to inefficiencies, which seems at odds with the sizable shocks due to weather, pest infestations, and other factors so characteristic of most agricultural production activities.

Unfortunately, the imprecision in the estimates reported by the literature does not allow conclusive answers to two very important questions concerning Argentina's agricultural sector, that is, whether TFP contracted or grew in recent decades, and whether the rate of change has slowed down or picked up pace over the same period. For this reason, efforts to predict the course of Argentinean agriculture's TFP in the future seem unwarranted at present.

7. CONCLUDING REMARKS

Argentina is a country richly endowed with natural resources appropriate for agricultural production. Such resources have allowed it to be a major player in international markets, despite the strong discrimination against agriculture that characterized the country's policies since World War II.

Existing studies have found mixed results regarding the performance of Argentinean agriculture in terms of total factor productivity growth. However, the experience from the 1990s, when discrimination against agriculture reached the smallest level in decades, strongly suggests that the sector is extremely responsive to economic incentives. The 1990s witnessed a massive adoption of modern technologies, the expansion of the crop frontier, an intensification of land usage in traditional areas, the advent of new forms of production organization, and substantial shifts from livestock to crops and among crops. More recently, feedlots have been widely adopted for beef production. During this period there were substantial gains in the productivity of land planted with major crops, and in the stocks of beef and (especially) dairy cattle.

The economic debacle experienced by Argentina at the end of 2001 marked a reversal toward more discriminatory policies against agriculture. The change was motivated by the country's dire need to obtain hard currency and improve fiscal revenues. Historically, the agricultural sector accounted for a significant share of the country's balance of trade and tax revenues, and that share increased following the economic crisis. The discrimination against the sector has become ever stronger since 2001, particularly after 2007. The current administration belongs to the party founded by Peron, who was instrumental in laying out and implementing the policies against agriculture and the welfare state that started after World War II. As such, despite losing mid-term elections in 2009 (arguably in part because of a confrontation with the agricultural sector), the current administration seems keen on reverting to the extent possible to the kinds of policies first instituted by Peron.

As of this writing, it seems unclear whether in the long run Argentina's agricultural policies will be as discriminatory as they were through much of the country's history and as they are now, or less so, as in the 1990s. The outcome will depend on how political forces shape up in the future. Importantly, the present discussion strongly suggests that such an outcome is likely to have critical implications for the future performance of Argentinean agriculture. The sector tended to languish when policies were highly discriminatory against it, but it quickly prospered under a more favorable economic environment.

Some recent studies conclude that Argentina has the potential to significantly increase its agricultural output over the next few years (e.g., Cap and González 2004; Oliverio and Lopez 2008). However, there are studies that also caution about the way agriculture has expanded in the recent past and/or question the sustainability of some of the current practices used in Argentina's production agriculture (e.g., World Bank 2006; Pineiro and Lopez Saubidet 2008). Paramount among these are the environmental issues connected with the conversion of natural ecosystems in marginal areas to agriculture, the high threat of soil degradation due to more intensive cropping, and the risks associated with having a single crop (soybeans) account for such a large share of the sector's output and trade.

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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

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[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:

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

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.

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[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.

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