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).

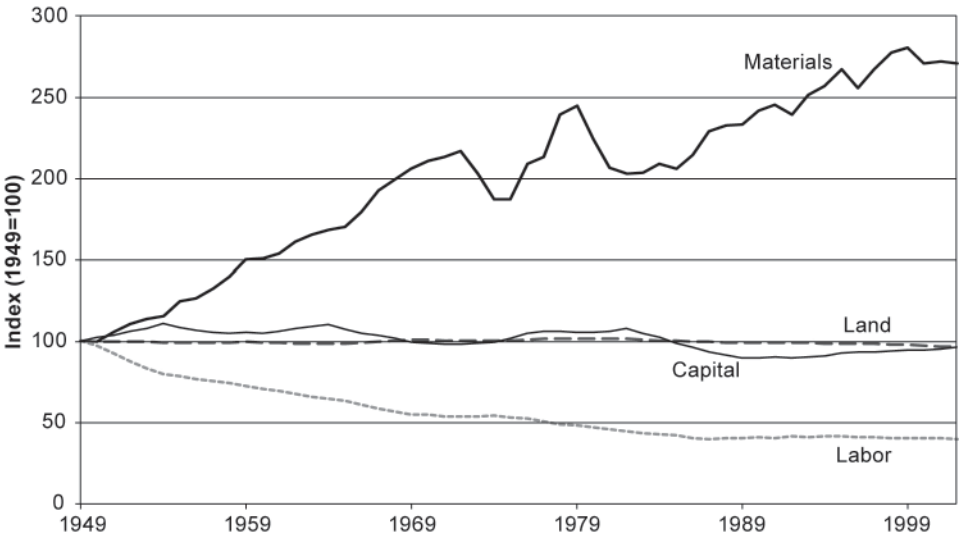

Figure 8.1. Quantity of capital and land services, labor, and materials inputs used in U.S. agriculture, 1949-2002

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

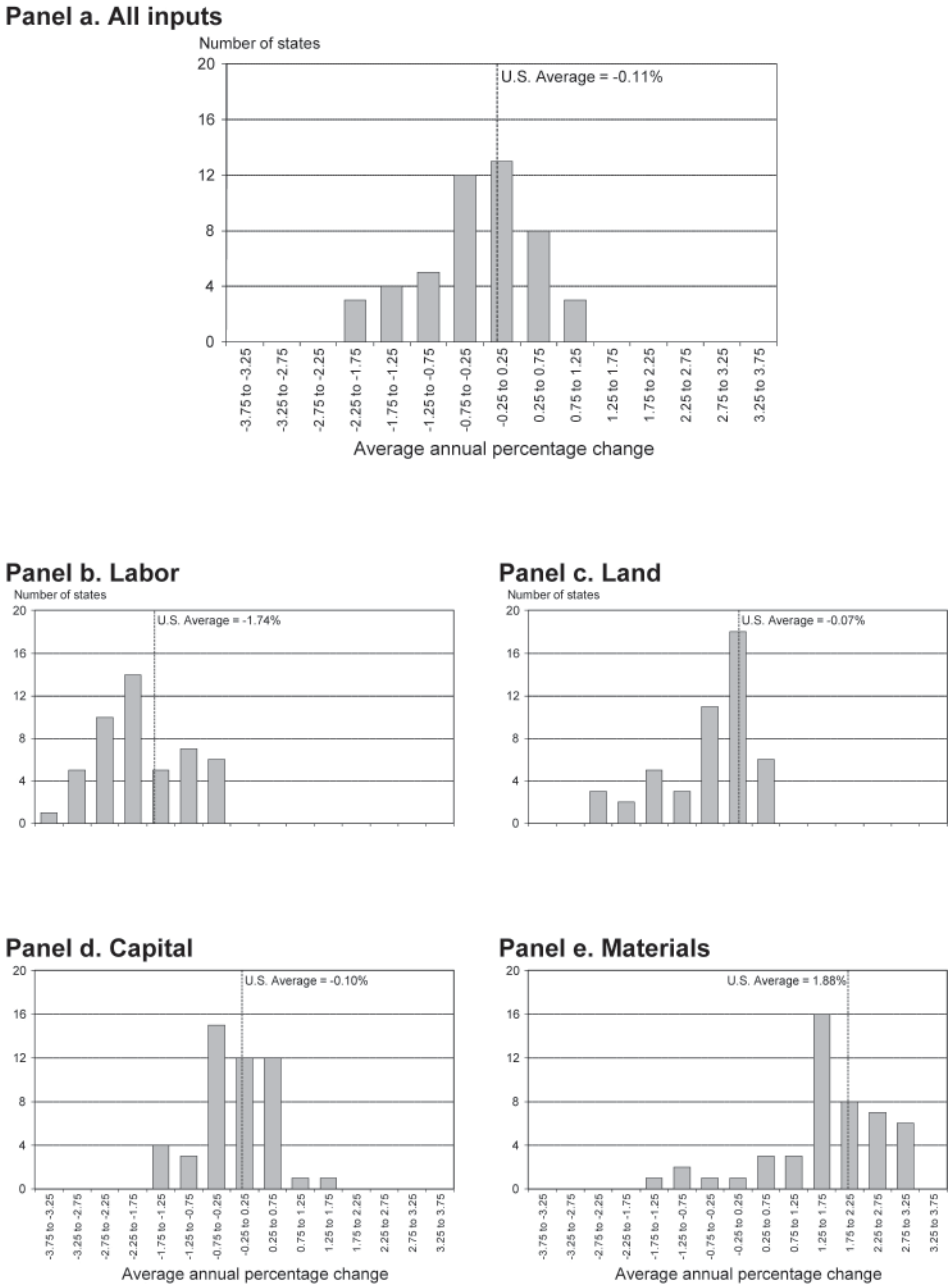

Figure 8.2. Distribution among states in the growth of input use, 1949-2002

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

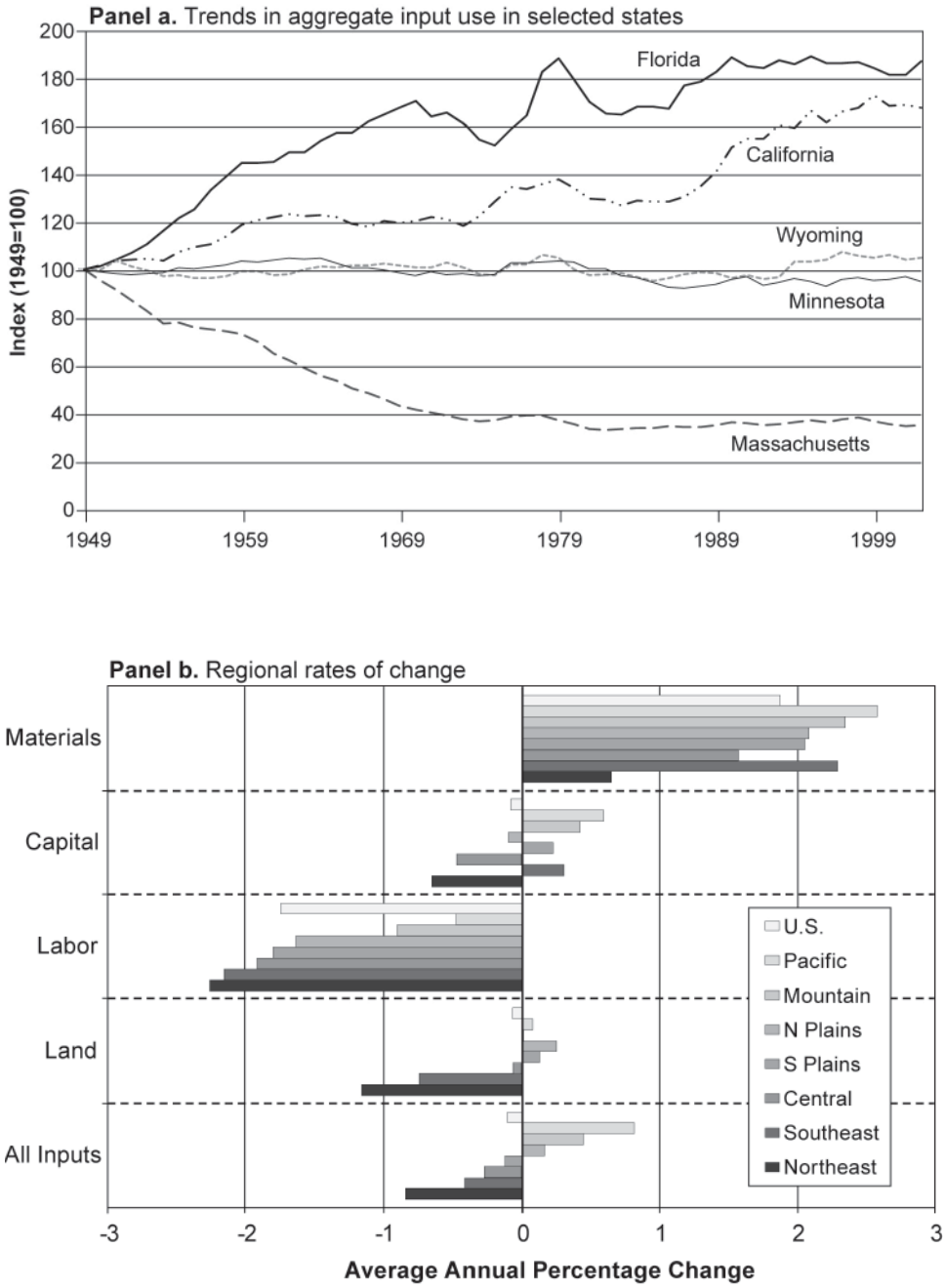

Figure 8.3. State and regional patterns of changes in input use, 1949-2002

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)	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)					
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 concen-

trated 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

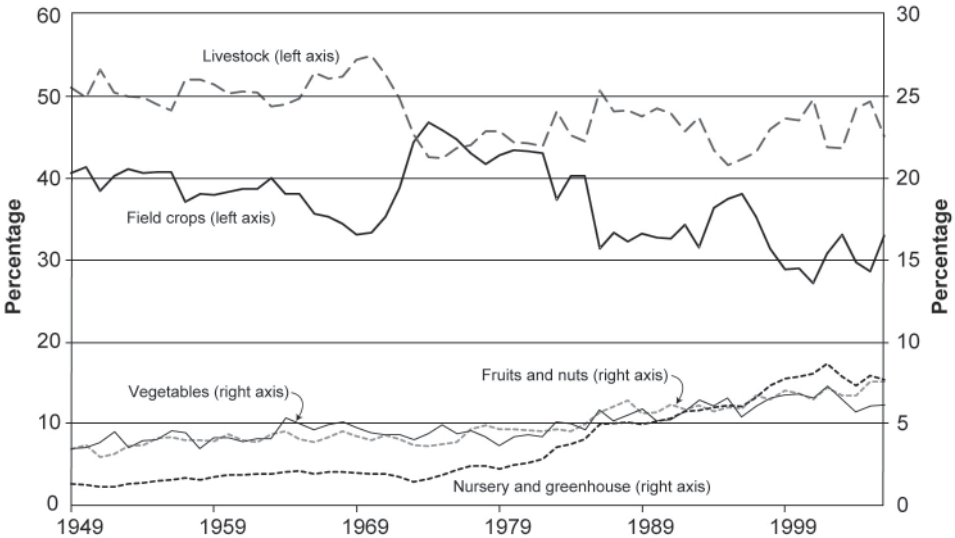

Figure 8.4. Value shares of output categories, 1949-2006
Source: Alston et al. 2010, based on InSTePP data.

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				Average Annual Growth Rate
Authors	Date	Method	Sample Period	(% 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	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

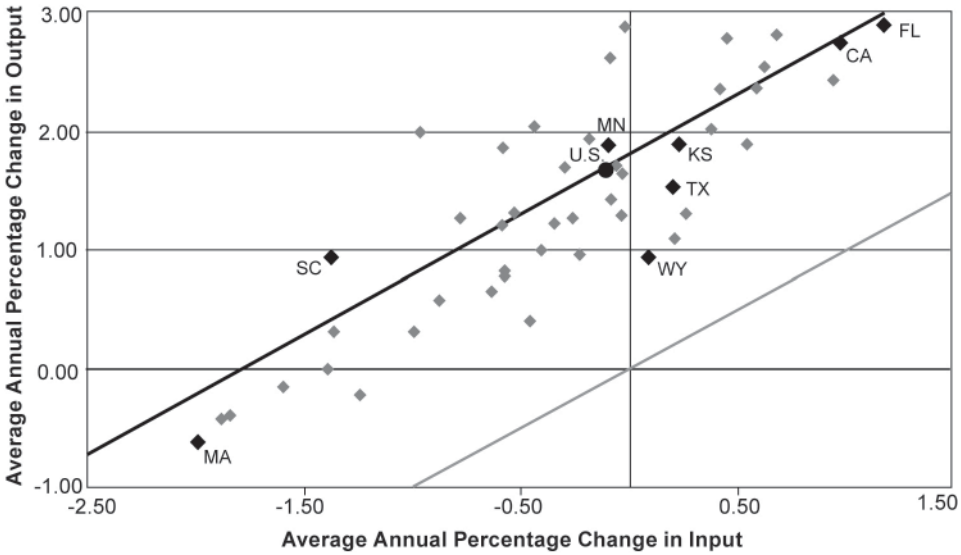

Figure 8.5. Input versus output growth rates, by state, 1949-2002
Source: Alston et al. 2010, based on InSTePP data.

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.

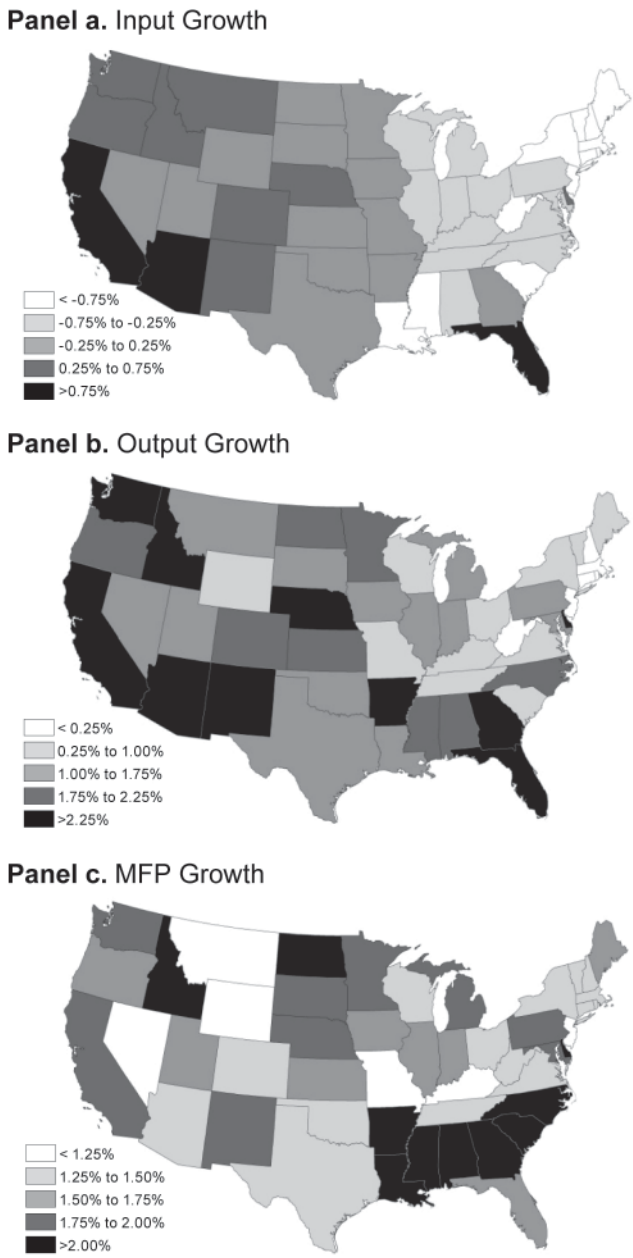

Figure 8.6. The geography of input, output, and productivity growth, 1949-2002

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.

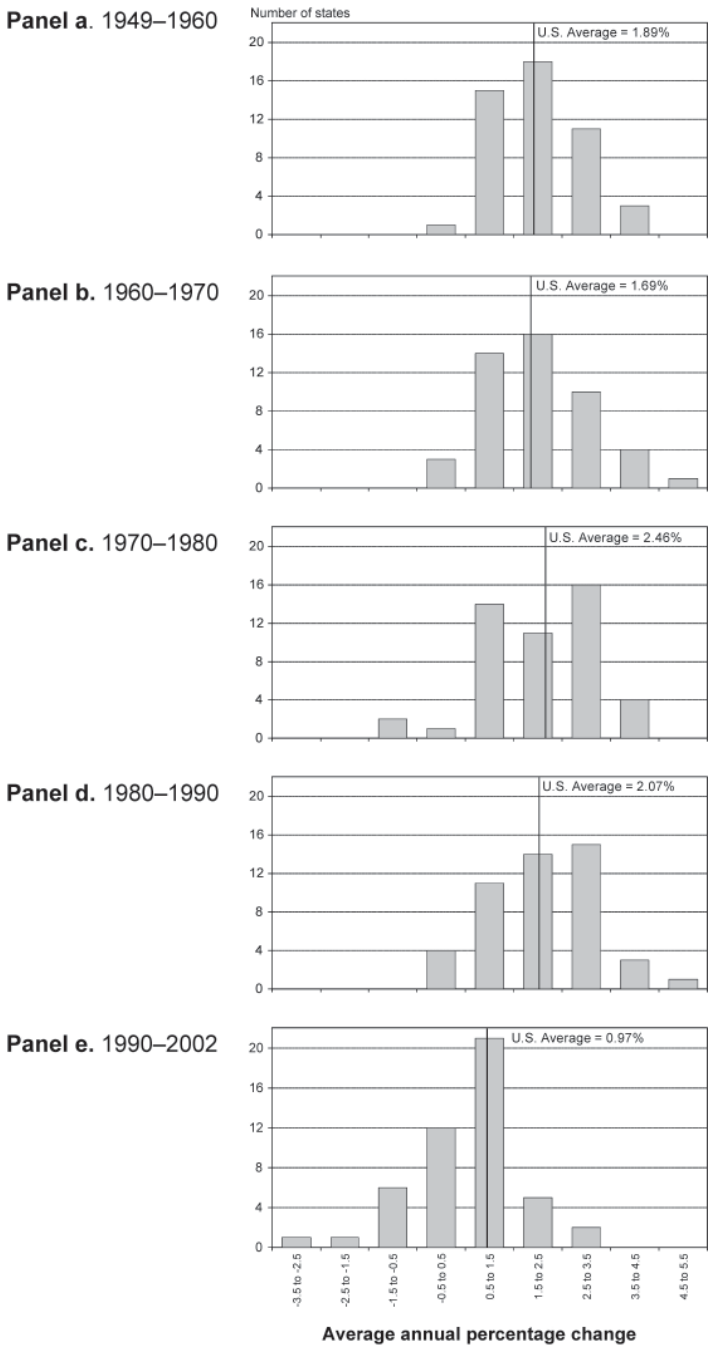

Figure 8.7. Distribution of average annual MFP growth rates across states, by decade

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

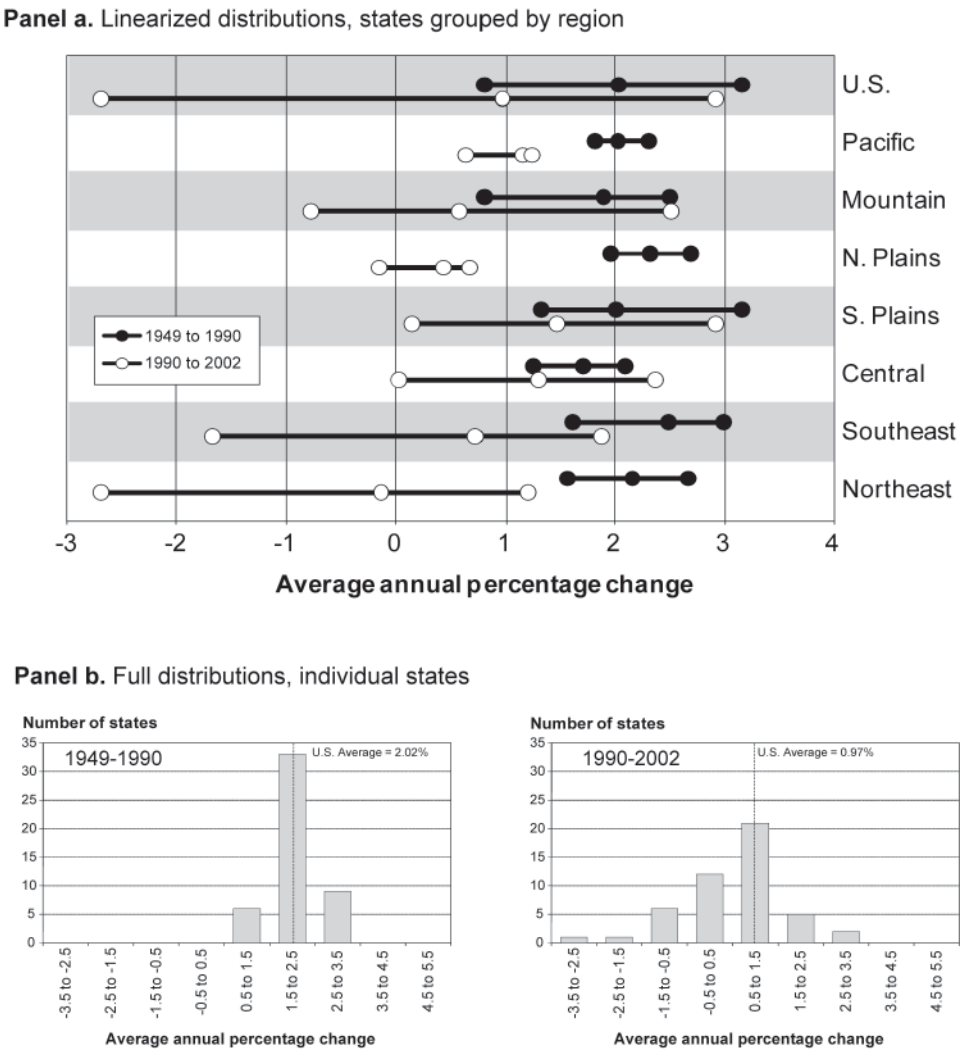

Figure 8.8. Distribution of MFP growth, 1949-1990 and 1990-2002

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.

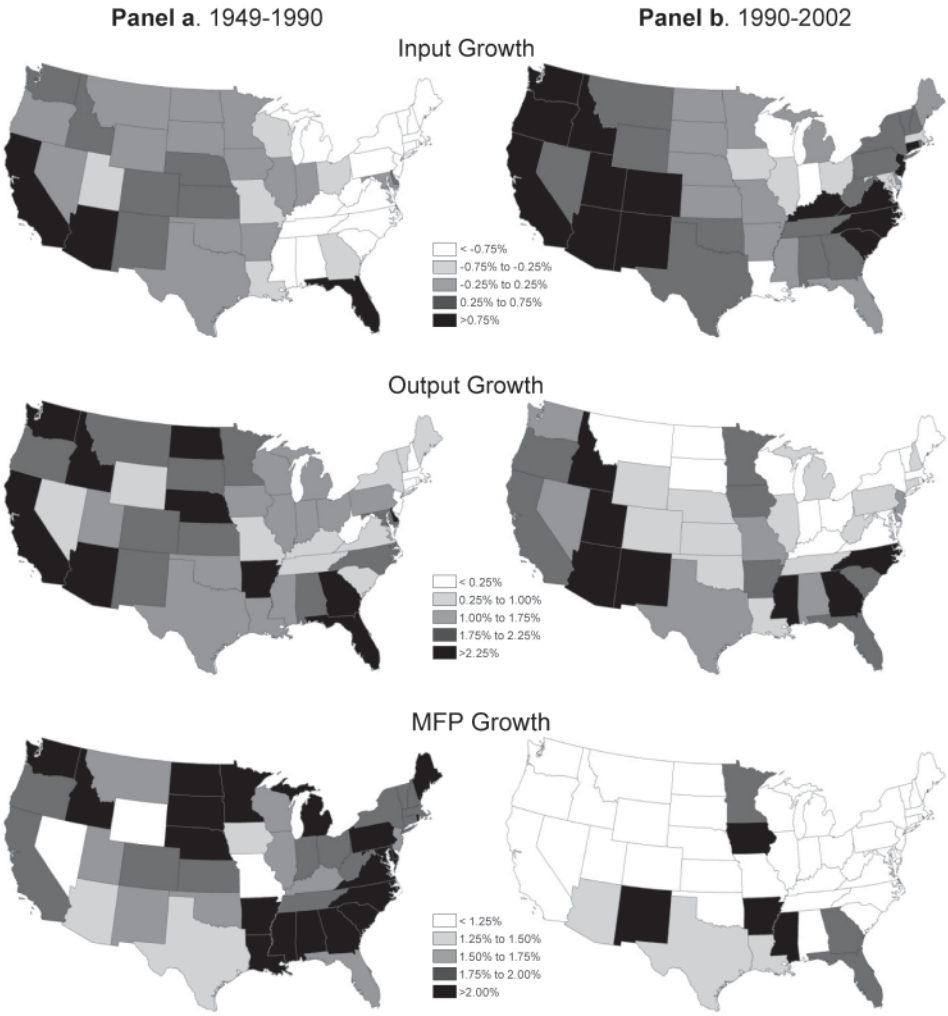

Figure 8.9. Input, output, and productivity growth rates, 1949-1990 versus 1990-2002

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.

REFERENCES

Acquaye, A.K. 2000. "Parametric and Nonparametric Measures of State-Level Productivity Growth and Technical Change in U.S. Agriculture: 1949-91." PhD dissertation, University of California, Davis.

Acquaye, A.K., J.M. Alston, and P.G. Pardey. 2003. "Post-War Productivity Patterns in U.S Agriculture: Influences of Aggregation Procedures in a State-Level Analysis." *American Journal of Agricultural Economics* 85(1, February): 59-80.

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

Alston, J.M., J.M. Beddow, and P.G. Pardey. 2009. "Mendel versus Malthus: Research, Productivity and Food Prices in the Long Run." Department of Applied Economics Staff Paper No. P09-1, University of Minnesota, September.

Andersen, M.A. 2005. "Pro-cyclical Productivity Patterns in U.S. Agriculture." PhD dissertation, University of California, Davis.

Andersen, M.A., J.M. Alston, and P.G. Pardey. 2007. "Capital Use Intensity and Productivity Biases." Department of Applied Economics Staff Paper P07-06/InSTePP Paper P07-02, University of Minnesota.

Andersen, M.A., J.M. Alston and P.G. Pardey. 2009. "Capital Service Flows: Concepts and Comparisons of Alternative Measures in U.S. Agriculture." Department of Applied Economics Staff Paper P09-8/InSTePP Paper 09-03, University of Minnesota.

Ball, V.E. 1984. *Measuring Agricultural Productivity: A New Look.* USDA Economic Research Service Staff Report AGES 840330. Washington DC: U.S. Department of Agriculture.

Ball, V.E. 1985. "Output, Input, and Productivity Measurement in U.S. Agriculture: 1948-79. *American Journal of Agricultural Economics.* 67(3, August): 475-486.

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

Ball V.E., J.-P. Butault, and R. Nehring. 2001. *U.S. Agriculture, 1960-96: A Multilateral Comparison of Total Factor Productivity.* Technical Bulletin 1895. Washington, DC: U.S. Department of Agriculture, Economic Research Service.

Ball, V.E., F. Gollop, A. Kelly-Hawke, and G.P. Swinand. 1999. "Patterns of State Productivity Growth in the U.S. Farm Sector: Linking State and Aggregate Models." *American Journal of Agricultural Economics* 81(1, February): 164-179.

Ball, V.E., C. Lovell, H. Luu, and R. Nehring. 2004. "Incorporating Environmental Impacts in the Measurement of Agricultural Productivity Growth." *Journal of Agricultural and Resource Economics* 29(3): 436-460.

Barton, G.T., and M.R. Cooper. 1948. "Relation of Agricultural Production to Inputs." *Review of Economics and Statistics* 30(2, May): 117-126.

Beddow, J.M., P.G. Pardey, and T.M. Hurley. 2009. "Space, Time and Crop Yield Variability: An Economic Perspective." Presented at the 53rd Annual Conference of the Australian Agricultural and Resource Economics Society (AARES), Cairns, Queensland, February.

Brown, R.S. 1978. "Productivity, Returns and the Structure of Production in U.S. Agriculture, 1947-74." PhD dissertation, University of Wisconsin.

Capalbo, S.M. 1988. "A Comparison of Econometric Models of U.S. Agricultural Productivity and Aggregate Technology." Chapter 5 of *Agricultural Productivity: Measurement and Explanation,* J.M. Antle and S.M. Capalbo, eds. Washington, DC: Resources for the Future.

Capalbo, S.M., and M. Denny. 1986. "Testing Long-run Productivity Models for the Canadian and U.S. Agricultural Sectors." *American Journal of Agricultural Economics* 68(3, August): 615-625.

Capalbo, S.M., and T.T. Vo. 1988. "A Review of the Evidence on Agricultural Productivity and Aggregate Technology." Chapter 3 in *Agricultural Productivity: Measurement and Explanation,* S.M. Capalbo, and J.M. Antle, eds. Washington, DC: Resources for the Future.

Cox, T.L., and J.-P. Chavas. 1990. "A Non-Parametric Analysis of Productivity: The Case of U.S. Agriculture." *European Review of Agricultural Economics.*17: 449-464.

Craig, B.J., and P.G. Pardey. 1996. "Productivity Measurement in the Presence of Quality Change." *American Journal of Agricultural Economics* 78(5, December): 1349-1354.

Dorfman, J.H., and K.A. Foster. 1991. "Estimating Productivity Changes with Flexible Coefficients." *Western Journal of Agricultural Economics* 16(2, December): 280-290.

Huffman, W.E., and R.E. Evenson. 1993. *Science for Agriculture: A Long-Term Perspective.* Ames, IA: Iowa State University Press.

Johnson, D.C. 1990. *Floriculture and Environmental Horticulture Products: A Production and Marketing Statistical Review, 1960-88*. Statistical Bulletin No. 817. Washington, DC: U.S. Department of Agriculture, Economic Research Service.

Jorgenson, D. 1990 "Productivity and Economic Growth." Chapter 3 in *Fifty Years of Economic Measurement: The Jubilee Conference on Research in Income and Wealth,* E. Berndt and J. Triplett, eds. Chicago: University of Chicago Press.

Jorgenson, D.W., and F.M. Gollop. 1992. "Productivity Growth in U.S. Agriculture: A Postwar Perspective." *American Journal of Agricultural Economics* 74(3, August): 745-750.

Karagiannis, G., and G.J. Mergos. 2000. "Total Factor Productivity and Technical Change in a Profit Function Framework." *Journal of Productivity Analysis* 14: 31-51.

Kendrick, J.W. 1983. "Inter-industry Differences in Productivity Growth." American Enterprise Institute.

Loomis, R.A., and G.T. Barton. 1961. *Productivity of Agriculture*. Technical Bulletin 1238. Washington, DC: U.S. Department of Agriculture, Economic Research Service.

Luh, Y.H., and S.E. Stefanou. 1991. "Productivity Growth in U.S. Agriculture under Dynamic Adjustment." *American Journal of Agricultural Economics* 73(4, November): 1116-1125.

McCunn, A., and W. Huffman. 2000. "Convergence in U.S. Productivity Growth for Agriculture: Implications of Interstate Research Spillovers for Funding Agricultural Research." *American Journal of Agricultural Economics* 82(2, May): 370-388.

Pardey, P.G., M.A. Andersen, B.J. Craig, and J.M. Alston. 2009. Primary Data Documentation U.S. Agricultural Input, Output, and Productivity Series, 1949–2002 (Version 4). InSTePP Data Documentation. International Science and Technology Practice and Policy Center, University of Minnesota.

Ray, S.C. 1982. "A Translog Cost Function Analysis of U.S. Agriculture 1939-77." *American Journal of Agricultural Economics* 64(3, August): 490-498.

Ruttan, V.W. 1956. "The Contribution of Technological Progress to Farm Output: 1950-1975." *Review of Economics and Statistics* 28: 61-69.

Schimmelpfennig, D., and C. Thirtle. 1999. "The Internationalization of Agricultural Technology: Patents, R&D Spillovers, and Their Effects on Productivity in the European Union and the United States." *Contemporary Economic Policy* 17(4, October): 457-468.

Star, S. 1974. "Accounting for the Growth of Output." *American Economic Review* 64(1): 123-135.

U.S. Bureau of the Census. 1956–1991. "Census of Horticultural Specialties [1954–1988]." *United States Census of Agriculture*. U.S. Department of Commerce. Washington, DC: Government Printing Office.

USDA (U.S. Department of Agriculture). Various years. *Agricultural Statistics*. Washington, DC: U.S. Department of Agriculture.

USDA-ERS (U.S. Department of Agriculture, Economic Research Service). 1991. *Economic Indicators of the Farm Sector: Production and Efficiency Statistics, 1989*. ECIFS 9-4, Washington, DC: Author.

———. 2007. "Farm Income." Data Sets. Washington, DC. http://www.ers.usda.gov/Data/FarmIncome/ (accessed November 2007).

———. 2008. "Agricultural Productivity in the United States." *Data Sets*. Washington, D.C.: http://www.ers.usda.gov/Data/AgProductivity/ (accessed June 2009).

USDA-NASS (U.S. Department of Agriculture, National Agricultural Statistical Service). 2000-2009. "Census of Horticultural Specialties [1998–2007]." *United States Census of Agriculture*. Washington, DC: Author.

U.S. Department of Labor, Bureau of Labor Statistics. 1992. Unpublished computer run on U.S. agricultural multifactor productivity, 1948-90.