5.1 Agricultural Productivity

Productivity, which measures the increase in outputs not accounted for by the growth in production inputs, is a closely watched economic performance indicator because of its contribution to a healthy and thriving economy. Agriculture, in particular, has been a very successful sector of the U.S. economy in terms of productivity growth. U.S. agricultural output grew at an average rate of 1.89 percent annually from 1948 to 1996, entirely due to productivity growth. In contrast, output growth in other sectors of the economy was largely from increased use of inputs. Productivity growth in agriculture can be attributed to investments in research and development (R&D), extension, education, and infrastructure.

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Productivity, which measures the increase in outputs not accounted for by the growth in production inputs, is a closely watched economic performance indicator because of its contribution to a healthy and thriving economy. Increasing levels of productivity bode well for the viability of the farm sector given the links among productivity, output prices, and competitiveness. Increased productivity can translate into increased farm income, at least in the short run. In the long run, additional farms adopt the more productive inputs and practices, leading to increased output supply and a possible lowering of farm output prices and farm income.

Agricultural output can grow from increased inputs and/or increased productivity (See box, "Types and Sources of Change in Agricultural Output"). The latter, usually expressed as total factor productivity (TFP), occurs when the ratio of total outputs to total inputs increases, reflecting greater average output per unit of input. (See box, "Measuring Total Factor Productivity"). Partial productivity measures, such as output per worker or acre, are also possible. (See box, "Measuring Partial Productivity")

The "conventional" approach used here to measure agricultural TFP includes only those outputs (crops and livestock) and inputs (labor, capital, and materials) that are under the control of the farmer and for which a market exists. This approach excludes "unconventional" inputs such as public agricultural research and "unconventional" outputs such as the effects of agricultural production on natural resource depletion and environmental degradation. Research is underway on approaches to estimate "unconventional" effects and to use the estimates to adjust the conventional output accounts.

Trends in U.S. Agricultural Productivity, Input Use, and Output

Total U.S. agricultural productivity grew at an annual average rate of 1.89 percent between 1948 and 1996, and was solely responsible for the growth in agricultural output of nearly the same magnitude (table 5.1.1 and fig. 5.1.1). Agricultural inputs in total actually declined by a 0.09 percent average rate during this period. Labor input use in agriculture declined over the period, while use of capital (durable equipment, real estate, and inventories) and intermediate inputs (fertilizer, pesticides, energy, feed, seed, and livestock) increased. The

Types and Sources of Change in Agricultural Output*

Changes in agricultural Outputs

Conventional market measured outputs:

Crops

Livestock

Nonmarket adjustments (when estimates are available):

Natural resource depletion

Environmental degradation

=

Changes in agricultural inputs

Conventional market measured inputs adjusted for quality:

Intermediate:
Fertilizer
Pesticides
Energy
Feed and seed
Livestock

Labor

Capital:
Equipment
Real estate
Inventories

+

Agricultural productivity growth

(Change in outputs not accounted for by the change in inputs)

Sources are:

Agricultural research and development

Extension

Education

Infrastructure

Government programs

* The traditional productivity numbers reported in this chapter measure conventional output per unit of conventional input.

Measuring Total Factor Productivity

Productivity measurement methods have evolved over time and will continue to evolve as they incorporate improved data and concepts (Hauver, 1989; Ball, et al., 1997; Ahearn, et al., Jan. 1998). A summary follows of key considerations and procedures used in estimating the productivity indicators presented in this chapter.

Choice of index procedure. An index number procedure is used to aggregate heterogeneous farm outputs and inputs. Dollars is the unit that allows for aggregation. But dollars must be adjusted to account for changes in the value of the dollars over time, plus changes in the relative prices of inputs and outputs over time. The economic theory of index numbers provides a link between various forms of index numbers and specific characteristics of production technologies, i.e., different types of production functions. Unfortunately, the index number procedures that currently exist correspond to only some of the simplest types of production technologies. Index number procedures that closely correspond to the real-world characteristics of U.S. agricultural production technologies simply do not exist. Hence, the choice of an index number procedure dictates the assumptions that are being made about the production function and by necessity limits the understanding of trends in TFP. A Tornqvist index is currently used to estimate agricultural productivity. In the past, the Laspeyres index, which uses base-period weights, was used in contrast to the Tornqvist, which uses prices from both the base period and the comparison period. The Tornqvist is preferred to the Laspeyres because it does not require the unrealistic assumption that all inputs are perfect substitutes in production.

Treatment of changes in input quality. Some inputs, such as agricultural pesticides have changed significantly over time. Defining and measuring quality presents a new set of challenges for the developer of productivity estimates. In general, characteristics of individual inputs have to be measured, along with the conventional quantities of individual inputs. In the case of pesticides, a quality characteristic of an individual pesticide is its ability to kill the targeted pest, which is related to the potency of the chemical. For many commonly used agricultural pesticides, potency, as indicated by reductions in pounds of the chemical applied per treated acre, has increased.

The current approach to dealing with variable input quality is to account for the quality changes in key inputs, where data availability permit, through a process of measuring the component characteristics of the input that are relevant to the observed quality changes. This approach was adopted because one of the most important uses of the estimates is to gain an understanding of the sources of growth in agricultural output. If the quality adjustments had not been made to the measured inputs, then the effect of these innovations would be captured in the TFP indicator, but not be disentangled from the other factors affecting TFP.

Treatment of labor. The labor index accounts for both changes in hours worked and in the quality of those labor hours. A quality-adjusted approach is used to account for changes in labor quality over time. Building on an approach developed by Gollop and Jorgenson, costs and quantities of labor input are cross-classified by the two sexes, eight age groups, five educational groups, and employment status. The cost of labor services is equal to wages plus supplements paid hired workers plus the imputed compensation to self-employed and unpaid family labor. The imputed wage of self-employed workers is set equal to the mean wage of hired workers with the same demographic characteristics. This treatment of labor differs from past USDA approaches that were based on the unweighted (by quality attributes) sum of hours worked.

Partial Productivity Measures

Historically, economists have used and developed productivity measures which are based on the relationship between one or more outputs relative to a single key input, such as an acre of farm land or an index of farm labor input. These indicators are called partial factor productivity indicators. The most common partial productivity index economy-wide is a labor productivity measure. The usefulness of a labor productivity measure for an industry varies depending upon the importance of the labor input in that industry. For agriculture, labor productivity measures can be misleading if used as the primary productivity indicator. This is because other types of agricultural inputs have been increasing at varying rates over time and because many work activities, previously performed on-farm, have now moved off-farm. For example, animal feed preparation used to be almost totally an on-farm work activity, while today the processing of animal feed is now a major off-farm work activity. The labor used in the off-farm processing of purchased animal feeds is not included in the farm labor input estimate. The labor-based partial productivity measures are the original of an oft-cited, but misleading, indicator of how many persons a U.S. farm worker feeds today compare with a previous time. For example, a U.S. farm worker was said to have supplied 96 persons with farm products in 1990, compared to 14 persons in 1948 (USDA, 1992). Accounting for the contribution of off-farm labor activity would significantly lower the number of farm products supplied by a farm worker.
Source: (Ahearn, et al., 1998)

inputs take into account quality changes, such as pesticides, land, and labor, where data availability permits. Output growth in crops (1.84 percent) averaged higher than output growth in livestock (1.66 percent).

Conditions facing the agricultural sector varied greatly over the 1948-96 period affecting productivity growth rates during sub-periods of time (table 5.1.1). During 1948-59, average productivity growth of 1.0 percent per year was lower than subsequent periods as agriculture and the whole economy readjusted after two major wars. The out migration of farm labor was significant during the period, and capital and intermediate inputs increased at very high rates, capturing the rapid movement toward mechanization on U.S. farms. This period also saw the increased application of scientific advances to farming: the use of hybrid seeds, adoption of improved livestock breeding, and the use of more agricultural chemicals, both fertilizers and pesticides.

During the 1960's, productivity growth averaged nearly twice that of the 1950's. Agricultural output growth for this period was below average (1.45 percent). Labor input continued to decline and there were moderate increases in intermediate inputs (with the exception of pesticides).

During the 1970's, demand for U.S. exports increased significantly and U.S. producers increased production to meet the demand. The average annual rate of growth in agricultural output exceeded 2.2 percent per year, with half of this due to productivity growth and just under half to growth in inputs (table 5.1.1). The average annual rate of 1.25-percent growth in productivity during the 1970's, however, was less than two-thirds of the growth rate of the 1960's. Growth in intermediate inputs averaged about 2.5 percent per year during the 1970's (Ahearn, et al., May 1998). Despite a three-fold increase in the price of petroleum fuels following the 1973 oil embargo, energy consumption in agriculture increased nearly 2 percent per year over the same period.

Table 5.1.1_Average annual growth in agricultural output, inputs, and productivity,1948-96, by periods

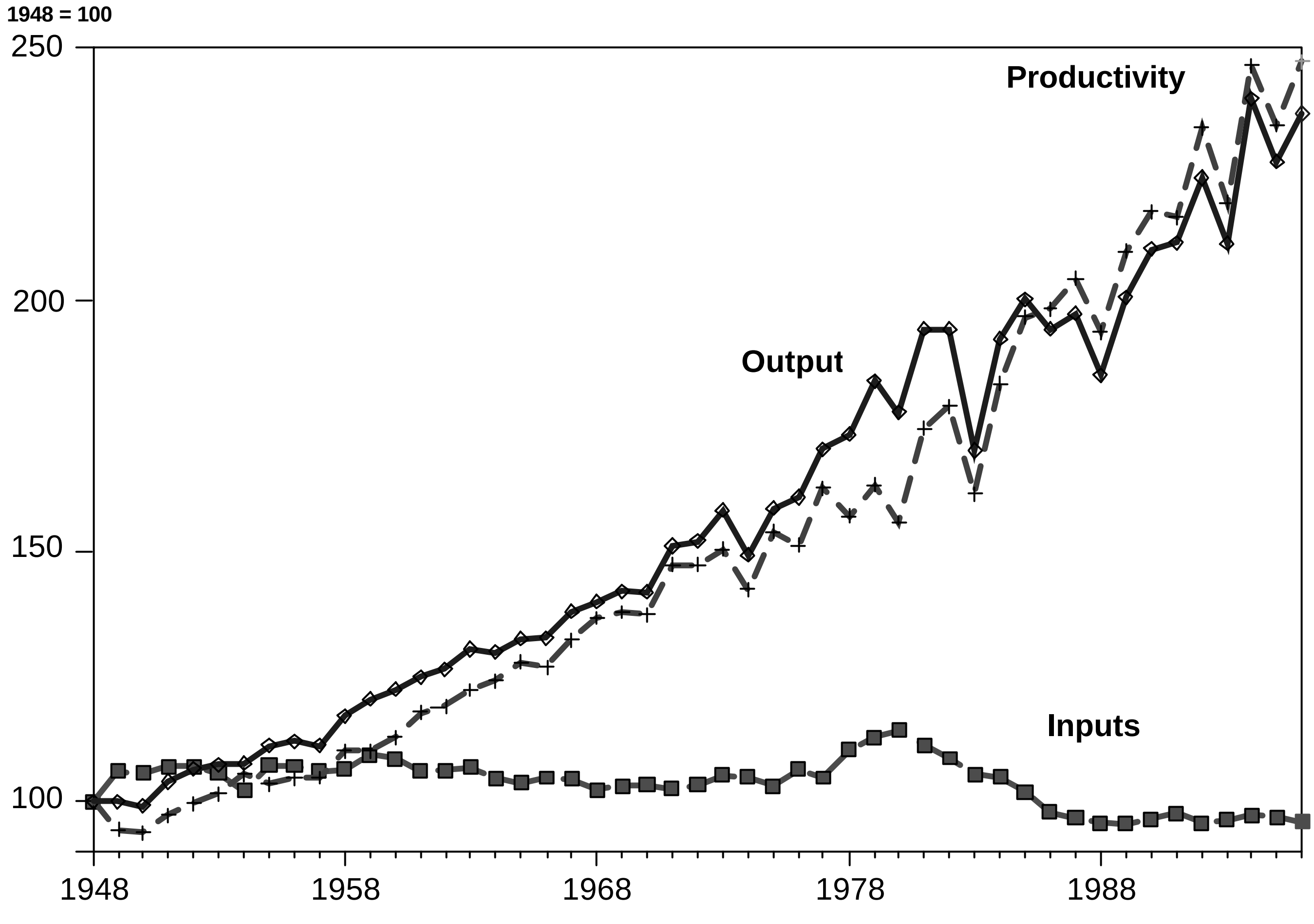
Index	1948-59	1960-69	1970-79	1980-84	1985-89	1990-96	1948-96
			Compound average annual growth rate (percent)				
Output	1.68	1.48	2.25	2.40	0.97	2.01	1.80
Livestock	2.45	1.62	0.95	0.82	1.33	2.28	1.66
Crops	1.02	1.29	3.20	3.40	0.65	1.81	1.84
Inputs	0.67	-0.48	1.00	-2.28	-1.07	-0.13	-0.09
Intermediate[1]	2.97	1.01	2.47	-2.95	0.33	0.45	1.25
Fertilizer	4.01	1.26	4.73	-5.73	-2.29	-1.46	1.23
Pesticides	11.40	8.68	5.98	0.26	1.44	2.68	6.42
Energy	1.96	1.16	1.85	-4.07	0.42	0.66	0.82
Feed, seed, livestock	2.20	1.59	2.05	-1.95	0.11	-0.64	1.03
Labor	-3.33	-3.36	-2.62	-2.56	-1.27	-0.28	-2.51
Hired	-2.85	-3.71	0.20	-4.46	-1.03	0.00	-2.02
Self-employed	-3.48	-3.27	-3.61	-1.93	-1.31	-0.63	-2.72
Capital	3.22	0.28	1.40	-1.52	-2.57	-0.88	0.62
Durable equipment	4.90	1.28	2.63	-3.47	-5.59	-2.78	0.75
Real estate	0.77	-0.53	0.66	-0.83	-1.26	-0.31	-0.04
Inventories	2.03	1.62	1.96	-1.22	-2.20	1.22	1.05
Productivity	1.00	1.96	1.25	4.68	2.04	2.14	1.89

NOTE: An electronic version of this data is located at the following website: "http://usda.mannlib.cornell.edu/data-sets/inputs/98003/"

[1] Includes other intermediate inputs in addition to those listed (Ahearn et al., 1998)

Source: Economic Research Service, USDA

Figure 5.1.1--Growth in agricultural productivity, output, and inputs, 1948-96



During the 1980's, short-lived concerns over food scarcity in the 1970's gave way to expectations of chronic crop surpluses. In 1983, the cropland area set aside (taken out of production) totaled 80 million acres as a result of the Payment-In-Kind program. Decreases occurred in all major input categories (but pesticides), as the agricultural sector scaled back production and went through financial restructuring. Although farm labor had consistently declined since 1948, capital (equipment and land) and intermediate inputs also declined during the 1980's. Total factor productivity, however, grew at record rates during the 1980's, averaging 4.68 percent in the first half of the decade, and 2.04 percent in the last half. The early 1990's saw a continuation of agricultural productivity and output growth averaging over 2 percent, while inputs again declined overall.

Larger shifts occurred in particular inputs over 1948-96. Although intermediate inputs (fertilizers, pesticides, energy, feed, seed, and livestock) as a group increased 1.42 percent per year over the period, energy inputs increased less than 0.9 percent while pesticides increased at nearly 5 percent per year. Synthetic pesticides were just beginning to be used in the late 1940's, but adoption occurred rapidly, and by the early 1970s, most acres in major crops were being treated. Total pounds of pesticides applied peaked in the early 1980's, and have been relatively stable since then (fig. 5.1.2). However, the mix of pesticides used has changed considerably, and, on average, their collective ability has improved to kill selected target pests, while reducing environmental and human health effects. These quality improvements in the pesticide input are captured in the pesticides index along with the changing quantity (Ball, et al., 1997) (see box, "Measuring Total Factor Productivity").

The labor index accounts for both changes in hours worked and in the quality of those labor hours. This adjustment for labor quality tempered the rate of decline in the labor input index (fig. 5.1.3) (Ahearn, et al., May 1998 and Ball, et al., 1997). In 1996, around 3 million people were employed in agriculture compared with approximately 7.6 million in 1948. While the workers employed and hours worked in agriculture have declined, the quality per hour worked has increased. For example, in 1964 only about one-third of all farmers had completed high school, compared with more than three-quarters of farmers by 1990.

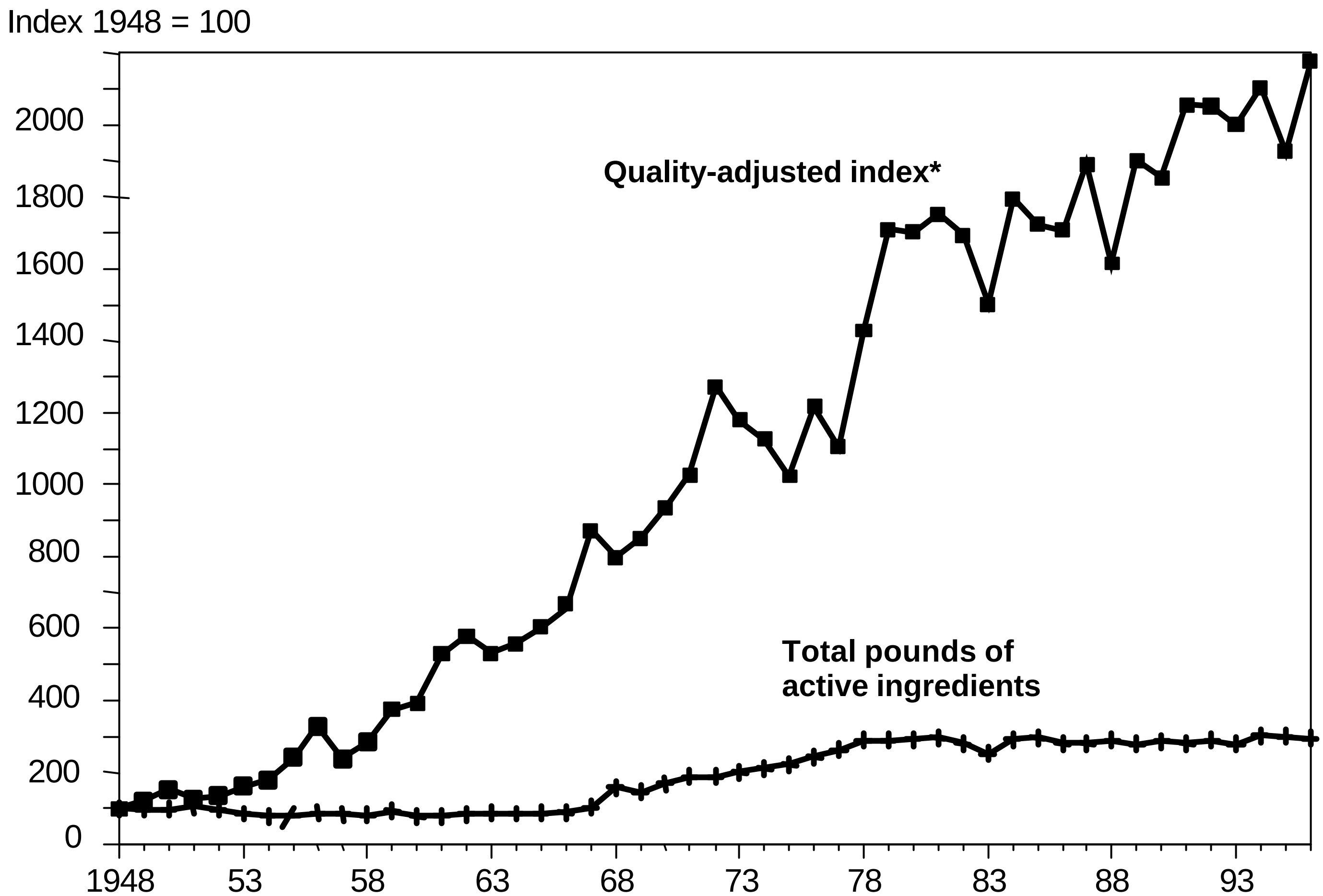
Agricultural Productivity Compared with Other Sectors

Agricultural productivity indicators can be compared with similar indicators in different sectors of the economy. An understanding of relative sector performance and the factors affecting that performance can help decision makers formulate public policies and private decisions to enhance productivity in slower growing sectors. For example, tax credits may be targeted to firms that invest in new equipment in slower growing sectors.

Agriculture's productivity performance in the U.S. economy is noteworthy. Agricultural productivity grew at 1.89 percent per year on average, for the period 1948-96, compared with 1.2 percent for manufacturing and 1.1 percent for non-farm business in general (fig. 5.1.4). In addition, productivity growth is a more important source of output growth in agriculture than it is for other industries. For example, while output growth in agriculture was entirely the result of productivity growth, output growth in the rest of the business economy was largely the result of growth in real (inflation-adjusted) dollars spent on inputs. For manufacturing alone—an industry considered to have relatively high rates of productivity and second only to services as an employer in nonmetro areas—only 40 percent of the increase in output growth came from productivity growth.

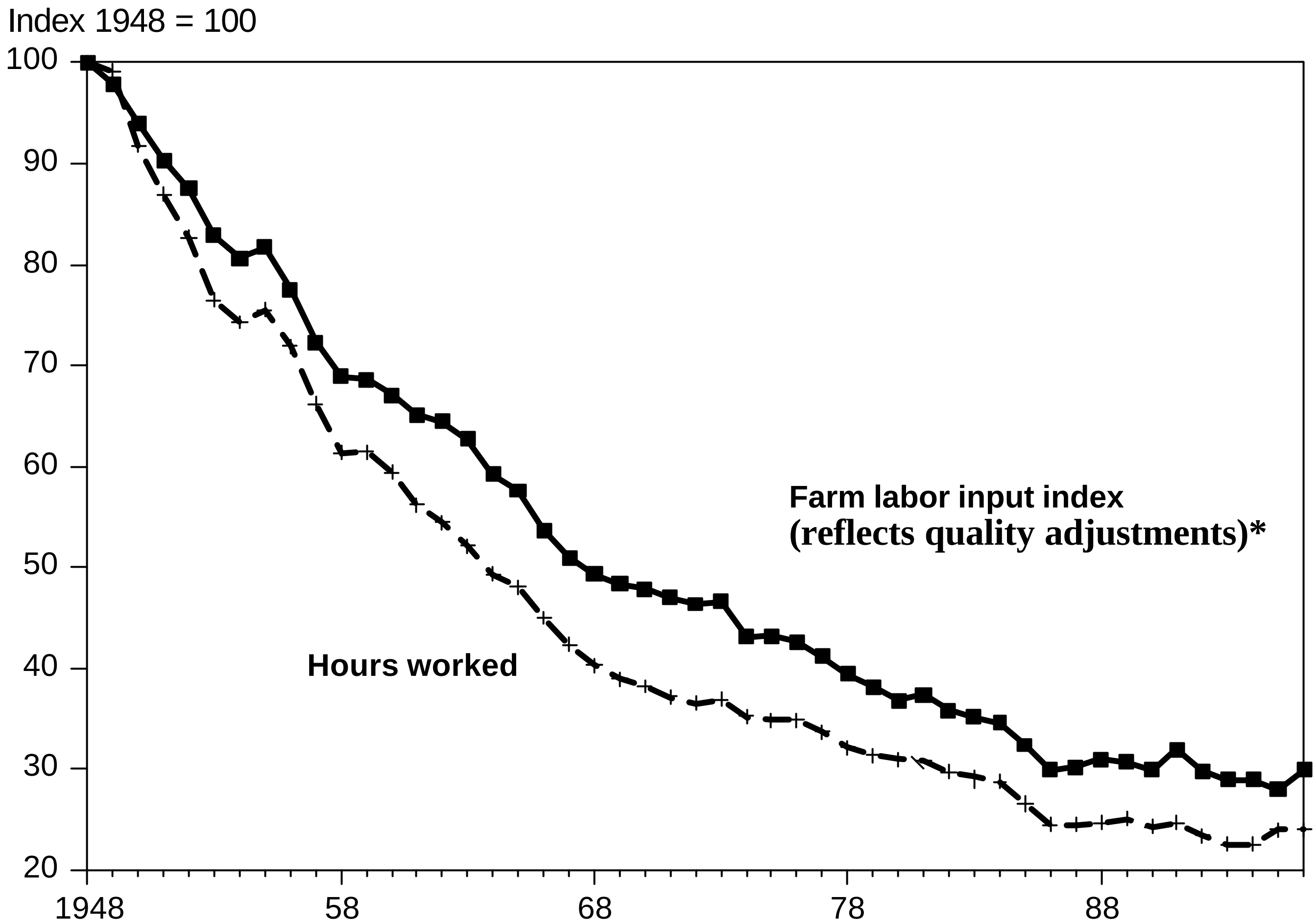
The food manufacturing sector has not experienced as high a level of productivity growth as has the agricultural sector. In fact, the average annual productivity growth rate of 0.5 percent in food and kindred products for 1949-96 was well below agriculture's high levels and below the average for all manufacturing combined (U.S.

Figure 5.1.2--Changes in pesticide use before and after quality adjustments, U.S. 1948-96



***Quality as denoted by fewer pounds of active ingredients needed per treated acre.**
Source: USDA, ERS, based on data from USDA-NASS and Doane Agricultural Service

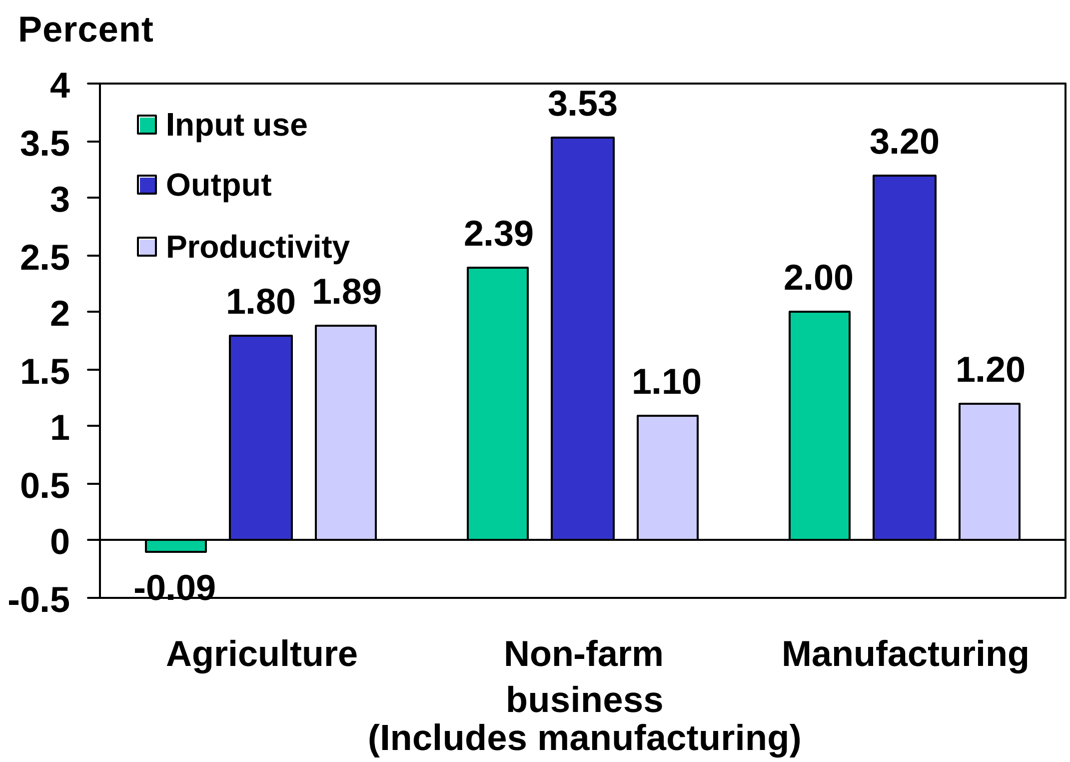
Figure 5.1.3--Labor input in agriculture, 1948-96



* Quality a function of education, age, gender, and full or part-time employment status

Source: USDA, ERS, based on data from USDA-NASS and Doane Agricultural Service.

Figure 5.1.4--Input use, output and productivity for agriculture compared with manufacturing and the non-farm business sector, 1948-96



Dept. of Labor, 1996). U.S. agriculture's high level of productivity tends to reduce the cost of commodity purchases for food manufacturers but is not fully translated into reduced consumer food prices because agriculture's share of our food bill is only about 22 percent. For every dollar spent on food, 22 cents is for farm products and 78 cents is for the food sector to process, package, and transport the product (Elitzak, 1996).

Differences Among States in Productivity Growth

National estimates mask differences in agricultural productivity, output, and input growth among individual States (table 5.1.2). Data on state level input, output, and productivity are available for the 1960-96 period. Over this period, most of the States with TFP growth rates higher than the 1.89 percent U.S. average were located in the eastern United States (fig. 5.1.5). Most of the states with low TFP growth rates were located in the West and Southern Plains. Three New England States and New Jersey experienced negative growth rates in real output over the time period. About two-thirds of the States experienced negative growth rates in input use during the period, reflecting the U.S. trend. (For more detailed information on state level productivity, output, and input indexes see Ball and Nehring, 1998, and electronic data files at http://usda.mannlib.cornell.edu/data-sets/inputs/98003/.) ERS is conducting research to investigate the reasons for variations in TFP across States. Understanding factors that influence growth within and across states can be used to formulate public policies and private decisions to enhance productivity.

Factors Affecting Agricultural Productivity

Several factors have been identified in the social science literature as the most important sources of productivity change in agriculture: research and development, extension, education, infrastructure, and government programs. Productivity measures do not provide any information about the separate role of each of these factors. However, an understanding of the potential sources of productivity growth is important for formulating appropriate policy tools to increase productivity and a society's standard of living.

Research and development

The results of agricultural research include higher yielding crop varieties, better livestock breeding practices, more effective fertilizers and pesticides, and better farm management practices. Agricultural research is required not only to increase agricultural productivity, but to keep productivity from falling. For example, yield gains for a particular plant variety tend to be lost over time because pests and diseases evolve that make the variety susceptible to attack. Thus, a large share of agricultural research expenditures is devoted to maintenance research.

Farmers benefit from agricultural research in the short run because of lower costs and higher profits. However, the long run beneficiaries of agricultural research are consumers who pay lower food prices. Agricultural research also helps the United States maintain its competitiveness in world markets. Agricultural research can also reduce inequality in incomes and living standards because lower food prices benefit low-income people more than high-income people. (Low-income people spend a larger share of their income on food than do high-income people.) Moreover, the major portion of public agricultural research is paid for by taxes from middle-income and high-income people.

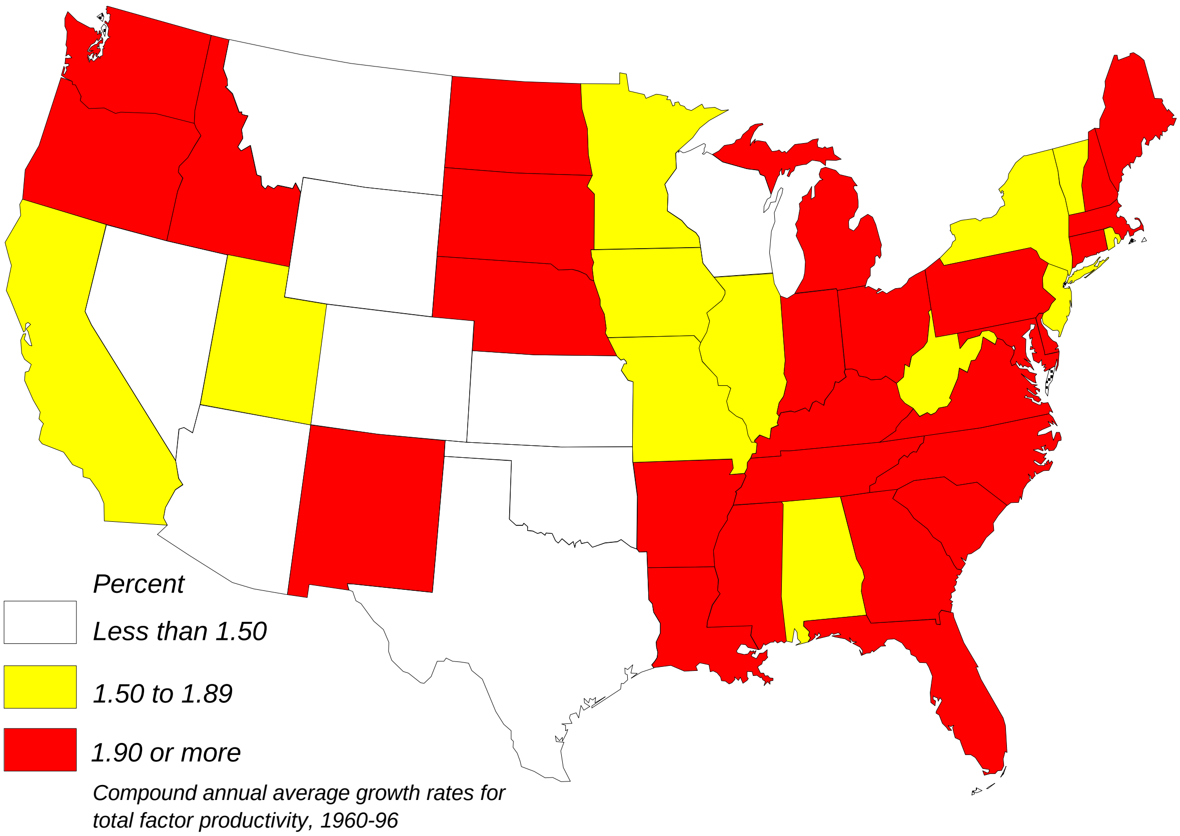
Agricultural research is performed by both the private and public sector. Private agricultural research expenditures have increased dramatically during the past three decades and now surpass those of the public sector, which have grown less (Fuglie, et al.) (See also chapter 5.2). Private agricultural research is performed mainly by manufacturers of farm machinery and agrochemicals, and by food processors. Public agricultural research is performed in State agricultural experiment stations, land grant and other universities, and the U.S. Department of Agriculture. Both public and private research have positive effects on agricultural productivity, with public research having a greater impact than private research (table 5.1.3).

Table 5.1.2 Total farm output, input, and productivity growth rates, 48 Contiguous States, 1960-96

States	Compound average annual growth rate (percent) Total farm output	Total farm input	Total factor productivity
Alabama	2.01	0.17	1.84
Arizona	1.38	-0.05	1.44
Arkansas	3.64	1.11	2.53
California	2.20	0.45	1.75
Colorado	2.05	0.65	1.41
Connecticut	0.70	-2.15	2.85
Delaware	2.89	0.97	1.92
Florida	2.69	0.57	2.12
Georgia	2.80	0.30	2.50
Idaho	2.67	0.33	2.34
Illinois	1.05	-0.63	1.68
Indiana	1.11	-0.87	1.98
Iowa	1.07	-0.60	1.67
Kansas	1.92	0.57	1.35
Kentucky	2.05	-0.40	2.46
Louisiana	2.48	-0.39	2.86
Maine	0.13	-1.95	2.08
Maryland	1.75	-0.22	1.97
Massachusett	-0.72	-2.85	2.13
Michigan	1.38	-1.23	2.61
Minnesota	1.55	-0.26	1.81
Mississippi	2.22	-0.42	2.63
Missouri	1.19	-0.55	1.74
Montana	1.49	0.07	1.42
Nebraska	2.57	0.58	1.99
Nevada	2.13	0.95	1.17
New Hampshire	-0.44	-2.49	2.05
New Jersey	-0.25	-2.02	1.77
New Mexico	2.60	0.46	2.14
New York	0.21	-1.32	1.54
North Carolina	2.29	-0.41	2.70
North Dakota	2.44	0.10	2.34
Ohio	0.90	-0.92	1.82
Oklahoma	1.44	0.44	1.00
Oregon	2.23	0.20	2.03
Pennsylvania	1.52	-0.71	2.23
Rhode Island	-0.76	-2.51	1.75
South Carolina	1.07	-1.30	2.37
South Dakota	1.75	-0.15	1.90
Tennessee	1.14	-0.78	1.92
Texas	1.77	0.41	1.36
Utah	1.69	-0.12	1.81
Vermont	0.41	-1.48	1.89
Virginia	1.47	-0.71	2.19
Washington	3.03	0.71	2.32
West Virginia	0.60	-1.25	1.85
Wisconsin	0.81	-0.61	1.42
Wyoming	1.21	0.24	0.97

Source:USDA,

Figure 5.1.5 -Farm productivity growth rates among the 48 contiguous States, 1960-96



Source: USDA, Economic Research Service

Table 5.1.3 - Social rates of return to agricultural R&D, extension, and education

Investment	Social rate of return
	Percent
All public agricultural R&D	40-60
Basic public R&D	60-90
Private R&D	30-45
Public extension	20-40
Farmers' education	30-45

Source: Fuglie, et al., table 7.

Extension

Agricultural research expenditures affect productivity after a time lag. First, a particular research project may take several years to complete. Second, it takes time for farmers to learn of and adopt the innovation. The sooner the benefits from research are received by farmers and consumers, the higher the rate of return to that research expenditure. The agricultural production extension system is aimed at reducing the time lag between the development of new technologies and their adoption. Extension agents disseminate information on crops, livestock, and management practices to farmers and demonstrate new techniques as well as consult directly with farmers on specific production and management problems. Unlike research, it is reasonable to assume that extension has an immediate effect on productivity.

Public extension expenditures have grown little in real terms since 1980 (Huffman and Evenson). The Federal share of public extension expenditures has fallen steadily during the past few decades. The bulk of extension services now come from State and county governments. The private sector has also begun to provide information to producers on new practices and technologies. For example, private crop consultants offer advice on pest and nutrient management practices. Farmers may also use farmer cooperative or chemical company representatives for advice on pest and nutrient management strategies.

Education

In contrast to the more applied focus of extension activities, education provides individuals with general skills to solve problems. Education is thus an investment in “human capital” analogous to a farmer’s investment in physical capital. Education hastens the rate of development of new technologies by training scientists. Education also speeds the rate of adoption of new technologies by farmers. Farmers who have more education may be better able to assess the merits of and successfully adapt a new technology to their particular situations. The current measure of labor input accounts for the changing educational attainment of the farm workforce over time. Gains in education accounted for 8.6 percent of the increase in output from 1948 to 1994 (Ahearn, et al., January 1998).

Another, though less obvious, effect of education is to help consumers better evaluate the potential risks posed by new products and technologies. The potential benefits of a new technology may not be realized if consumers do not buy products using the new technology. Meat with livestock growth hormones, irradiated food products, and genetically modified varieties are cases in point. Firms may be hesitant to develop a new technology if regulatory approval or consumer demand for products using the technology are uncertain.

Infrastructure

A few studies have found a significant positive relationship between infrastructure and U.S. agricultural productivity (Gopinath and Roe; Yee, et al.). The most obvious example of how public investment in infrastructure might affect agricultural productivity is through investment in public transportation. An improved highway system can reduce the farmers’ cost of acquiring production inputs and of transporting outputs to market.

Government Programs

The role of government in the agricultural sector is pervasive. Government programs affect productivity through the allocation of resources and outputs. Government farm programs are the most common example of government involvement in agriculture. But other examples are numerous: Tax policy may be used to encourage private firms to invest in the development of innovations and farmers to adopt the innovations. Enhanced intellectual property rights protection may increase the incentives for private firms to engage in private agricultural research. Regulatory policies affect the rate at which new drugs and farm chemicals reach the market place. Although relatively little research has investigated the impact of government farm programs on agricultural productivity, some of the few studies found a significant positive relationship (Huffman and Evenson, 1993). For example, direct government payments may encourage substitution of improved capital inputs for labor and increase the rate of new technology adoption. (Makki, et al.)

Social Rates of Return to Agricultural Research, Extension, and Education

Most studies have been consistent in finding high rates of return to society from public investment in agricultural R&D, usually in the 40 percent to 60 percent range (Fuglie, et al.) (table 5.1.3). The high rates of return to public agricultural R&D emerge regardless of the level of aggregation (individual commodities or more aggregate measures) or geographical area considered. Also the rate of return to public agricultural R&D is higher than the rates of return to other investment impacting agricultural productivity, such as public extension, private R&D, and farmers' education. More studies of the rates of return to different public investments are needed to assist public decision-makers to intelligently allocate the limited funds.

Future Prospects

Research, extension, education, infrastructure, and government programs will continue to affect the productivity of U.S. agriculture. However, the magnitude of their effects is uncertain because the relationships between these factors and productivity are still not well understood and because of the uncertainty surrounding the level at which society will invest in these growth sources and programs. There is also a great deal of uncertainty about how the agricultural sector will adjust to the provisions of the 1996 Farm Act, which phases out commodity programs that have been in place for more than 60 years. The U.S. agricultural sector has demonstrated its ability to be flexible to market signals like the unfavorable economic environment in the 1980s and to make needed production adjustments.

Authors: Doris Newton (202-694-5619, dnewton@ers.usda.gov) and Jet Yee (202-694-5611, jyee@ers.usda.gov)

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