Prospects for Productivity Growth in U.S. Agriculture

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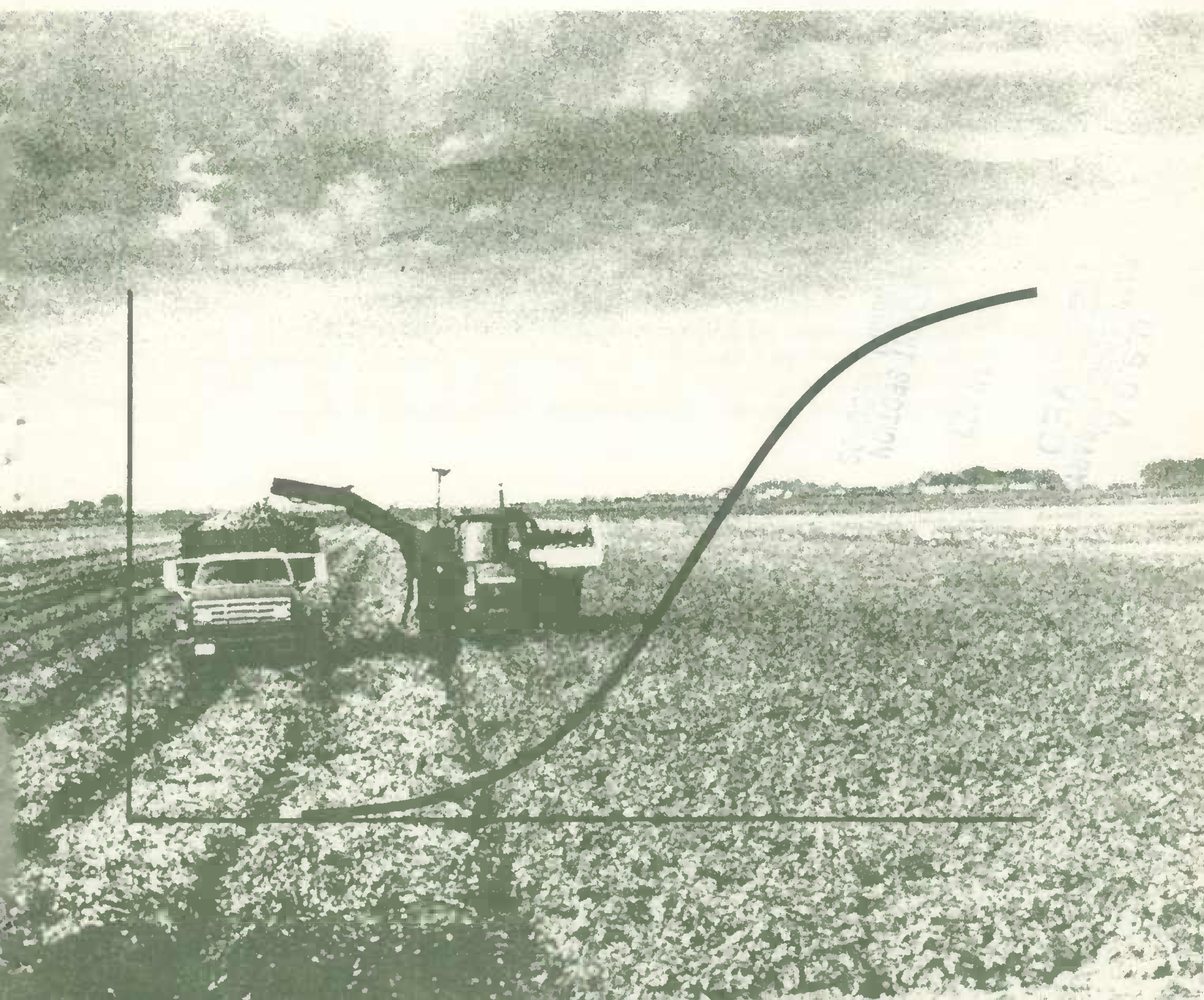

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ABSTRACT

The growth rate for U.S. agricultural productivity through the year 2000 may equal the historical rate if research and extension (R & E) investment increases and unprecedented technologies develop. The level of public expenditures in agricultural R & E is the single most important policy variable in determining growth rates. The most promising new technologies are photosynthesis enhancement (formation of plant carbohydrates through exposure to light), bioregulators (compounds which promote ripening or prolong shelf life) in crop production, and twinning in beef cattle production.

KEYWORDS: Productivity, technology, research and extension, simulation, projection.

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SUMMARY

U.S. agricultural productivity will continue to grow through the turn of the century. However, the rate of growth may decline—to 1.1 percent—if only the historical rate of support for research and extension (R & E) is maintained and no new and unprecedented technologies emerge. Increased agricultural R & E support and reasonable success in R & E programs could generate a productivity growth rate by 2025 equal to the rate during the past half-century—1.5 percent.

This study analyzes results from three scenarios for future productivity growth. Different rates of public support are assumed for agricultural R & E. Under a low technology scenario in which nominal public expenditures for agricultural R & E are just offset by inflation, the annual productivity growth rate by 2000 is about 1 percent—below the rate of the last 50 years.

Under a baseline scenario in which real R & E grows 3 percent annually, the historical average since the beginning of World War II, the annual growth rate is about 1.1 percent.

Under a high technology scenario in which real R & E is assumed to grow 7 percent annually and emerging new technologies—such as photosynthesis enhancement and bioregulators in crop production and twinning in beef cattle production—become commercially available for adoption, the growth rate is 1.3 percent.

As most of these new technologies would not be available for adoption until the 1990's, their full impact on agricultural productivity would not be realized by 2000. However, if the high technology scenario is projected to the year 2025 to allow more time for widespread adoption of the new technologies, productivity can be expected to maintain the 1.5-percent historical growth rate.

Technology is the major force behind productivity growth. If the state of technology is constant, productivity will eventually reach its limit to growth.

In earlier epochs, which were characterized by a single power source (human power or horse power), limits to productivity growth were reached. By contrast, in the current period of advanced scientific knowledge, major technologies are synergistic—that is, their combined use stimulates greater productivity than the sum of the productivity of each used separately. This synergistic relationship suggests that technology itself can be considered a resource. Unlike natural resources, technology is manmade and can be continuously increased through research and development. The probability of a limit to agricultural productivity growth is thereby further reduced.

Because the leadtime in research is lengthy and the adoption process for unprecedented new technologies takes decades to complete, agricultural productivity may appear initially unresponsive to both increased R & E support and emerging technologies. For example, a 1-percent increase in R & E would increase U.S. agricultural productivity gradually, would reach its peak impact 6-7 years later, and would influence productivity for the following 6 years, with the annual impact ultimately becoming negligible. Total average lagged impact would be 13 years. The estimated lag lengths for the 10 farm production regions vary from 9 years in the Pacific to 14 years in the Lake States.

The study also estimates that a 1-percent increase in the level of educational attainment by farmers would increase agricultural productivity about three-fourths of 1 percent, a significant growth when measured in terms of the actual dollar value of increased farm output.

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INTRODUCTION

This study explores the possibilities of expanding the growth rate for U.S. agricultural productivity, which declined during the sixties. We seriously question the hypothesis that agricultural productivity will reach a "limit to growth" by the turn of the century. Under three scenarios for research and extension (R & E) expenditures, we project future agricultural productivity growth for the United States and its 10 farm production regions. We also examine the impacts of the development of unprecedented new technologies on future growth paths. Our findings should prove useful to those persons in the Federal and State Governments in a position to effect policies and programs related to agricultural R & E, technical and social scientists engaged in the conduct and evaluation of agricultural R & E programs, and decisionmakers in the private sectors of our complex food and agricultural system for which agricultural productivity growth is an important consideration.

Our major reason for studying agricultural productivity growth is that world population and income growth is expected to cause major longrun increases in world food demand. At the 1976 National Academy of Sciences' Bicentennial Symposium on "Science, a Resource for Humankind," Moeen Queshi of the International Finance Corporation estimated that the developing countries' 2.8 billion population will reach at least 4.8 billion by the turn of the century, whereas the population of the developed countries will increase from 1.2 billion to 1.5 billion (*49*).[1] To feed this growing world population, even at current nutritional levels, annual world food-grain production must increase from the current 1.3 billion metric tons to about 2.0 billion metric tons. If nutritional gains are to be made in developing countries, annual food-grain production will have to reach about 3.0 billion metric tons.

This critical situation relates directly to the longrun capacity for a greater U.S. agricultural output. There are several options.

First, the United States could increase cropland acreage. Although the potential for raising output in the short run (1-2 years) by increasing land input is not great, there are potentially 266 million acres of noncropland suitable for regular cultivation. Of this total, about 96 million acres have a medium to high potential for conversion within 10-15 years. If these 96 million acres were cultivated by 1985, grain sorghum acreage could double, cotton and citrus acreage could increase by two-thirds, wheat by two-fifths, soybeans by one-third, and corn by approximately one-fifth. However, choosing this option might decrease pastureland by 60 million acres (*13*).

The second option for increasing output is through greater use of capital inputs such as fertilizers, insecticides, pesticides, and machinery. The proportion of agricultural chemicals to total farm inputs increased from 3 percent in 1950 to 16 percent in 1975. Most of this gain resulted from a fivefold increase in chemical fertilizer use. Farm feed, seed, and livestock purchases also increased—from 8 to 14 percent of total inputs.

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[1] Italicized numbers in parentheses refer to literature cited in the reference section at the end of this report.

Third, agricultural output could be increased through greater productivity of farm inputs—the option analyzed in this study. Greater agricultural productivity can help mitigate the world food situation, slow food price inflation, help conserve natural resources, improve the working and living conditions of farmers and farmworkers, and help offset possible limitations on farm output resulting from environmental constraints or possible unfavorable long-term climatic changes.

The growth rate for U.S. agricultural productivity began to slow in the sixties after two decades of accelerated growth. From 1939 to 1960, total factor productivity—as measured by output per unit of all inputs—increased 2.0 percent annually, and labor productivity grew at 5.9 percent. However, from 1960 to 1970, total factor productivity increased only 0.9 percent annually, and labor productivity rose 5.6 percent (*77*).

Some analysts believe that the limit to agricultural productivity growth has been reached. In observing productivity growth curves in recent years, James G. Horsfall and Charles R. Frink of the Connecticut Agricultural Experiment Station concluded that the rapid expansion of the Nation's ability to produce more and more food seems to have peaked, and growth curves tracing historical expansion are flattening (*73*). Glenn Salisbury, Director of the Illinois Agricultural Experiment Station, noted that local corn yields rose from 70 bushels an acre in 1955 to 130 bushels in 1965, but they have dropped to 120 bushels in the last 10 years. After discussions with leading agricultural scientists, Victor McElheny concluded that the Nation may be living off past technological breakthroughs (*3*).

Historically, economic analysts have tended toward one of two extreme attitudes to the world food situation—feast or famine. With amazing regularity, the prevailing attitude swings from the position that agriculture has an inherent capacity for overproduction to the view that scarcity is a permanent characteristic of food production. Recently, the pendulum had swung from the chronic overproduction thesis held by Heady and others (*27*) and Johnson and Quance (*29*) to the scarcity antithesis of Brown (*8*) and Renshaw (*57*). As a result of several bountiful grain harvests and growing grain stocks, the pendulum is now again moving toward the position of abundance.

Hathaway (*26*) has observed that, in the sixties, the world in general and Americans in particular were complacent about food supplies. This attitude was never shared by those millions who live on the edge of starvation or malnutrition. Yet the developed countries' capacity for high technology agriculture and the "green revolution" in developing countries had led many people to adopt a global surplus psychology. Indeed, world grain production—the foundation of the world food supply—rose almost every year during 1960-72, interrupted only by poor crops in the USSR in 1961 and 1963 and by the great Indian drought of 1965-66. This steady growth occurred despite U.S. production control programs.

Recently, however, we have witnessed severe turbulence in the world food and agricultural systems: severe famine in the sub-Sahara and in other food-deficit developing countries; the Arab oil boycott and skyrocketing prices for energy supplies to U.S. agriculture; massive grain purchases by the USSR occasioned by poor weather; a worldwide economic slowdown in many nonoil-exporting countries; and more recently, excess grain supplies, low farm prices, a farm "strike," and persistent inflationary pressures.

Moveover, in the United States, agricultural production is becoming more and more unnatural. Energy, chemical fertilizers, pesticides, and irrigation water are being used in increasingly concentrated food-production processes. As environmental concerns move into the forefront of public interest in agriculture, the formerly rapid rise in agricultural productivity has begun to slow down.

Accelerations in agricultural exports during the late sixties and early seventies, coupled with slower productivity growth and strong production controls, caused surplus commodity stocks to dwindle and prices to rise. Americans witnessed limited beef supplies in the supermarkets, wheat prices of $5 per bushel, soybean prices exceeding $12 in the Chicago futures market, and food price increases of 14 percent annually from 1972 to 1974 and 6.8 percent annually from 1974 to 1978. These changes resulted in a decrease in per capita food consumption for the first time since 1967 and an increased public demand for a national food policy.

These developments have also led to new questions about U.S. agriculture's capacity to maintain adequate food supplies in domestic and world markets in the future. The United States is currently the major supplier of the poor nations and one of the most promising sources for their expanding imports. Faced with higher outlays for oil and other imports, the U.S. Government is relying on large grain exports to help balance international accounts. U.S. consumers, shocked by inflation in general, want to know if increasing grain exports will lead to higher food prices, and farmers want information on future farm commodity supply-demand conditions to make better decisions about their increasingly capital-intensive and high-input cost businesses (*6*).

In light of the findings of this reasearch, the limits to growth attitude of some analysts is too pessimistic, although there are legitimate concerns. The following questions are posed in this report: What is agricultural productivity? How has it changed in the past? How much is agricultural productivity likely to grow by the turn of the century? How might emerging technologies change productivity growth?

CONCEPTS AND MEASUREMENTS

This section reviews productivity concepts and describes methods by which total factor productivity (output per unit of all inputs) can be computed. It examines the difficulties in estimating a production function and in using it to measure productivity change. It also derives an arithmetic index, or formula, for measuring agricultural productivity—that is, the effectiveness with which farmers combine their resources to produce agricultural commodities. A change in productivity as computed by the arithmetic formula is equivalent to the ratio of the index of total output to the index of total input.

Productivity is a widely used but misunderstood concept. Even among economists, the meaning of productivity differs. To some economists, productivity means output per man-hour; to others, it means output per unit of all inputs used in production. To avoid confusion, we begin this section with a discussion of the concept of productivity.

Productivity Concepts

Productivity measures the technical efficiency with which resources are converted to commodities and services. Land, labor, fertilizer, machinery, insecticides, seeds, energy, and other capital inputs are used to produce food and fiber for human consumption. Agricultural productivity measures how effectively farmers combine these resources. Increased agricultural productivity enables a farmer to produce more food and fiber with the same amount of resources. For example, 40 years ago, an American farmer produced enough food to feed 11 people. Today, one farmer produces enough food to feed 59 people—44 at home and 15 abroad.

There are two types of productivity: partial productivity and total factor productivity. The ratio of output to a single input is called the partial productivity of that input, and the ratio of output to all inputs combined is called total factor, or multifactor, productivity.

As partial productivity relates output to a single input, there are many partial productivities, such as labor productivity, capital productivity, land productivity, and others. Whereas each particular productivity index (or the ratio of output to a particular input) has its own use, the most important and most commonly used partial productivity measure in agriculture is labor productivity. For example, the familiar "how many people a farmer can support" is labor productivity.

Labor productivity is a popular measure of productivity because labor is one of the most important production factors, data on man-hours are readily available, and the partial productivity index is simple to compute and easy to comprehend.

If its limitations are recognized, labor productivity is a useful index. It is a good measure of efficiency if all other resources constitute a small fraction of total inputs or if the amount of other resources remains unchanged. Although, in the past, labor constituted a large fraction of total inputs in U.S. agricultural production, this fraction has declined steadily over time. In 1939, for example, labor constituted 54 percent of total inputs, but in 1978, this percentage declined to 13. Therefore, labor productivity does not measure the efficiency with which resources are converted into food and fiber. Nor does it measure the efficiency with which labor is utilized, because higher output per man-hour can be, and usually is, achieved by increasing the use of machinery, fertilizer, and other capital equipment as well as increasing labor efficiency.

Thus, today's farmer can produce enough food to feed more people than in the past, not only because he is more efficient than his father but also because he uses more fertilizers and insecticides and better machines than his father used. As there are ways other than labor efficiency by which a farmer can increase productivity, all inputs should be considered when measuring productivity.

Productivity Measures

Partial productivity can be measured simply by taking the ratio of output to a single input, with both numerator and denominator measured in physical units or in constant dollar money values. In addition, to facilitate comparison over time, the ratios are normally converted to an index.

Measuring total factor productivity is more complex. The first difficulty is that of constructing the aggregate input as a divisor. Disparate quantities of inputs such as hours of work, acres of land, pounds of fertilizer, and numbers of tractors must be combined to produce a single aggregate input measure. To overcome this difficulty, economists use real monetary value as a common unit of input measure.

The next problem in computing total factor productivity is that of selecting the weighting method for combining inputs. In general, two approaches have been used: index numbers and production functions.

Production Functions

A production function describes a physical relationship between a firm's input of resources and its output per unit of time under a given state of technology. Ideally, if the form of the production function is fully specified, this functional relationship can be employed to combine all inputs used in production into an aggregate input. Unfortunately, the true form of this production function is unknown. Use of the popular Cobb-Douglas function, or the constant-elasticity-of-substitution (CES) production function, imposes these particular functional forms on production relationships, but this may not represent their true relationship. A more nearly ideal way to determine the form of the production function is to fit a generalized production function form to the data and to determine the specific form by testing the values of the production function coefficients.

Lu (*41*) fitted a variable-elasticity-of-substitution (VES) production function to U.S. agricultural data for 1939-72. The VES production function is a generalized form which includes linear, Cobb-Douglas, CES, and linear-elasticity-of-substitution (*58*, *62*) functions as special cases (*43*). The specific form can be determined by testing the elasticity of subsitution of the estimated VES function.

Lu's results indicate that the underlying production function for U.S. agriculture during 1939-72 is of the Cobb-Douglas form. The shortcoming of the Lu study is that the VES function includes only two input variables. It is difficult, if not impossible, to extend the function to allow for more variables.

Since the introduction of the VES production function, many other generalized production functions such as generalized power production function (*14*), nonhomogeneous production function (*72*, *78*), homothetic production function (*48*, *63*, *79*), and transcendental logarithmic production function (*9*) have been introduced. Each functional form has contributed greatly to the study of production theory but, like the VES function, all have limitations. The nonhomogeneous production function, for example, can be estimated with more than two input variables. However, because of interaction terms in the function, the number of terms multiply exponentially as the number of input variables increase. Thus, estimation becomes difficult. As a special case of a nonhomogeneous production function, the transcendental logarithmic production function shares the same difficulty.

Even if the production function form can be specified, there are other problems. Production function coefficients represent a given state of technology. When technological change takes place, these coefficients also change. As changes in technology are neither smooth, nor continuous, nor necessarily neutral, it is difficult to capture the true shifts of the production function in a specific functional form.

Index Numbers

As in U.S. agriculture there are numerous input variables and as many inputs have been increasing over time, multicollinearity is always present in time series. The problem is even more severe when interaction terms are included in the estimated function. For practical purposes, therefore, the production function approach is not suitable for measuring U.S. agricultural productivity. An alternative is the index number approach.

Two common index number methods use arithmetic and geometric formulas. The arithmetic formula combines inputs arithmetically with input prices as weights by simply adding individual inputs weighted by their prices. A productivity index computed with this formula is called an arithmetic index. Kenderick (*31*) used this formula to estimate total factor productivity in U.S. industries.[2] The official U.S. Department of Agriculture (USDA) agricultural

[2] Recently, Kenderick (*32*) used factor shares rather than factor prices as weights.

productivity index has also been computed with this formula since the Loomis and Barton (*39*) study on productivity of U.S. agriculture.

The geometric formula combines inputs geometrically with factor shares as weights. Solow (*67*) used this formula in a study of technical change in the United States for 1909-49. In studying such change in U.S. agriculture from 1950 to 1966, Nevel (*51*) also used a similar approach.

Although no production function form is explicitly assumed in the above two methods, they imply production functions. Use of an arithmetic index implies that the underlying production function is linear (see the next section). An aggregate input index based on a geometric formula implies a Cobb-Douglas production function. These index number approaches are, therefore, special cases of the production function approach (*41*).

Two studies indicate that the arithmetic index is at least as good as the geometric index. Comparing the productivity indexes using these two index number approaches, Kendrick (*32*, p. 15) indicates that "the difference in results of the alternative weighting procedures would not generally show up over the subperiods when the productivity growth rates are rounded to tenths of percentage points." In studying the relationship between the two measures, Kleiman, Halevi, and Levhari (*34*) conclude: (1) that the arithmetic index is preferable to the geometric index because the former is a measure of the shift of the production function, which is unaffected by changes in the capital-labor ratio, and (2) that it measures what the geometric index says should be measured. Furthermore, the arithmetic index is simple to calculate and easy to understand. It is also used to measure productivity in other industries. Using the same measure makes agricultural productivity comparable with statistics for other industries. Therefore, this study will use the same arithmetic index as reported by USDA (*77*).

However, the arithmetic index is not an ideal index. It yields an exact measure of productivity change only under very restrictive conditions. To understand these conditions, let us consider the derivation of the arithmetic index from a production function.

Derivation of the Arithmetic Index

The arithmetic index formula can be derived from the functional distribution of income, assuming a linearly homogeneous production function. To simplify the analysis, only two factors of production are presented. Nevertheless, the argument can easily be extended.

Consider the following production function:

$$Q = f(K,L) \tag{1}$$

where Q = physical output

K = physical capital input

L = labor input.

If the production function is homogeneous of degree one (that is, there are constant returns to scale), then by Euler's theorem:

$$\begin{aligned} Q &= \frac{\partial f}{\partial K} K + \frac{\partial f}{\partial L} L \\ &= MP_K \cdot K + MP_L \cdot L \end{aligned} \tag{2}$$

where MP_k and MP_L are marginal products of capital and labor, respectively. Multiplying both sides of the above equation by the price of output (P) yields:

$$PQ = P \cdot MP_K \cdot K + P \cdot MP_L \cdot L \tag{3}$$

or:

$$V = VMP_K \cdot K + VMP_L \cdot L$$

where V is the value of output and VMP is the value of marginal product. If agriculture is operating competitively, the factors of production are paid the values of their marginal products, that is:

$$VMP_L = W,$$

$$VMP_K = r,$$

where r is the price of capital and w is the wage rate. Equation (3) then can be rewritten as:

$$V = r \cdot K + w \cdot L \tag{4}$$

Equation (4) is the arithmetic formula used to aggregate inputs in computing the official USDA productivity index. This equation is linear and homogeneous. The isoquant[3] is also a linear equation, and the elasticity of substitution between capital and labor is infinity.

At the base period, equation (4) becomes:

$$V_0 = r_0K_0 + w_0L_0 \tag{5}$$

and at period 1:

$$V_1 = r_1K_1 + w_1L_1 \tag{6}$$

where the subscript denotes the time period.[4] Had the production function and factor marginal productivity (or equivalently, the price weights) remained the same from the base period to period 1, the same quantity of inputs in period 1 (K_1 and L_1) would have produced:

$$V_1^* = r_0K_1 + w_0L_1 \tag{7}$$

V_1^* is the value of output which *would have been produced* with the inputs in period 1 (K_1 and L_1) *had the technical condition remained the same as* that of the base period, and V_1 is the value of output *actually produced* with inputs K_1 and L_1 under the technical condition in period 1. *Thus, the ratio of V_1 to V_1^* measures the effect of the change in technique from the base period to period 1.*

[3] An isoquant is the locus of all combinations of two inputs that yield a specified output level.

[4] This section benefits from the idea in Barzel (*5*).

Let P_{01} denote a change in productivity from the base period to period 1; then:

$$P_{01} = V_1/V_1^* \tag{8}$$

Dividing (7) by (5) gives:

$$\frac{V_1^*}{V_0} = \frac{r_0K_1 + W_0L_1}{r_0K_0 + W_0L_0}$$

or

$$V_1^* = V_0 \cdot \frac{r_0K_1 + W_0L_1}{r_0K_0 + W_0L_0} \tag{9}$$

By substituting (9) into (8), we obtain:

$$P_{01} = \frac{\dfrac{V_1}{V_0}}{\dfrac{r_0K_1 + W_0K_1}{r_0K_0 + W_0K_0}}$$

which is equivalent to:

$$P_{01} = \frac{\text{Index of total output}}{\text{Index of total input}}$$

Thus, the arithmetic index can be derived from a linearly homogeneous production function.

HISTORICAL CHANGES IN AGRICULTURAL PRODUCTIVITY

The classical S-shaped growth curve is employed to illustrate the typical pattern with which new agricultural technologies are adopted by U.S. farmers. U.S. agricultural productivity in the last 200 years is viewed as a series of four successive growth curves characterized by their respective sources of power—human power, horse power, mechanical power, and science power. We argue that modern technology, unlike the power resources of previous epochs, is a man made resource which can be continually increased through research and development. Science power can loosen the constraints imposed by finite natural resources and thus can further reduce the probability of a limit to agricultural productivity growth.

When a new technology becomes commercially available, its initial effect on agricultural productivity is generally small for two reasons. First, because the possible payoff of a new technology is uncertain, only a few farmers will try it out. Second, these early adopters require time to evaluate it (stage 1). As early adopters benefit from using the new technology, more and more farmers are attracted to it. As a result, productivity grows at an increasing rate (stage 2). Eventually, however, the growth rate declines as most farmers adopt the new technology and as its potential use is exhausted (stage 3). At this point, the limit to growth under the new technology has been reached. Thus, productivity grows along a classical S-shaped growth curve, as shown in figure 1.

However, as productivity reaches or approaches its limit to growth under a given state of technology, other new technologies may emerge. Emergence of a new technology causes productivity to break through the limits imposed by the old technology and thereby shifts productivity growth to a new S-shaped curve. Let us use this hypothesis to explain historical productivity growth in U.S. agriculture.

Figure 2 illustrates changes in agricultural productivity during the past 200 years. Although productivity has fluctuated from year to year, long-term growth patterns are evident. Modifying an analysis by Rasmussen (*56*), who divided the last 200 years of U.S. agricultural history into three periods, we have divided it into four periods according to the major sources of technological change: the American Revolution to the Civil War (human power), the Civil War to World War I (horse power), World War I to World War II (mechanical power), and World War II to the present (science power).[5] We have identified an S-shaped growth curve for each period. The productivity growth curve for the past 200 years can be viewed as four successive S-shaped growth curves.

The American Revolution to the Civil War: Human Power

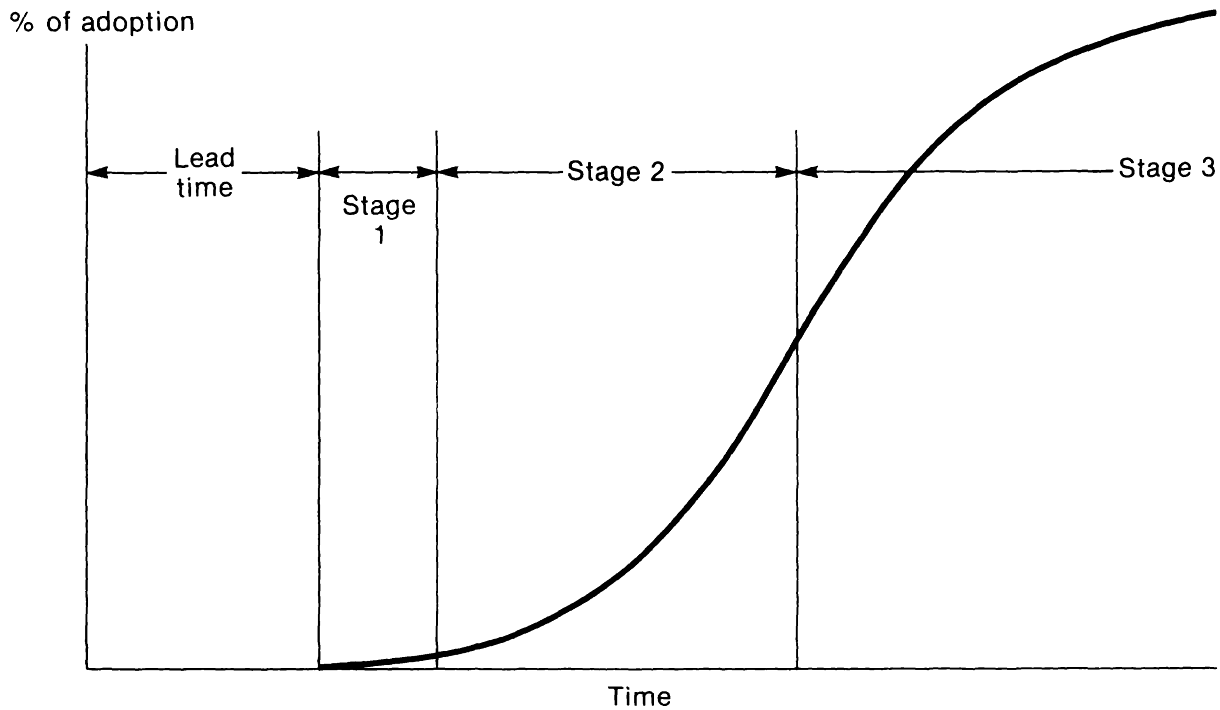
At the time of the American Revolution, most farming tools differed little from those used during the previous two centuries. After the Revolution, however, American leaders such as George Washington and Thomas Jefferson searched for better implements and more productive farming methods (*56*). They invented and adopted many improved farming practices, tools, and machinery, including the cotton gin, cast iron ploughs, mechanical reapers, and mixed fertilizers. As a result, productivity increased. Nevertheless, because farming practices, tools, and machinery were basically hand-powered, productivity reached its limit to growth under hand power technology toward the end of the period. Although there are no real measures of agricultural productivity during this period, we concluded that productivity grew very slowly in the late 1700's and early 1800's but leveled off about 1830 as illustrated by the dotted line in figure 2.

Toward the end of this first epoch, many labor-saving machines including horse-drawn

[5] This analysis benefits from Rasmussen (*56*) and is reported in Lu and Quance (*44*) and Lu (*42*).

Figure 1

S-Shaped Curve



reapers, grain drills, corn shellers, hay-baling presses, and cultivators of various types were invented. However, because the new machines were expensive relative to labor, farmers lacked incentive to invest in the new technology.

The Civil War to World War I: Horse Power

The Civil War stimulated change from hand power to animal power and thrust American agriculture into its first revolution (*56*). A war-induced labor shortage, high demand, and resulting high food prices encouraged farmers to adopt labor-saving horse-drawn machines. During this period, several farm programs and policies were implemented to generate new knowledge and to disseminate it to farmers. In 1862, the U.S. Department of Agriculture (USDA) and the Land Grant Colleges in each State were established to teach farmers new farming practices and to encourage their adoption. Passage of the Hatch Act in 1887 established agricultural experiment stations in each State to generate new technologies, and the Smith-Lever Act of 1914 created and charged the Cooperative Extension Service with disseminating knowledge about new technologies. Nationwide, county agents taught farmers about new machines and practices.

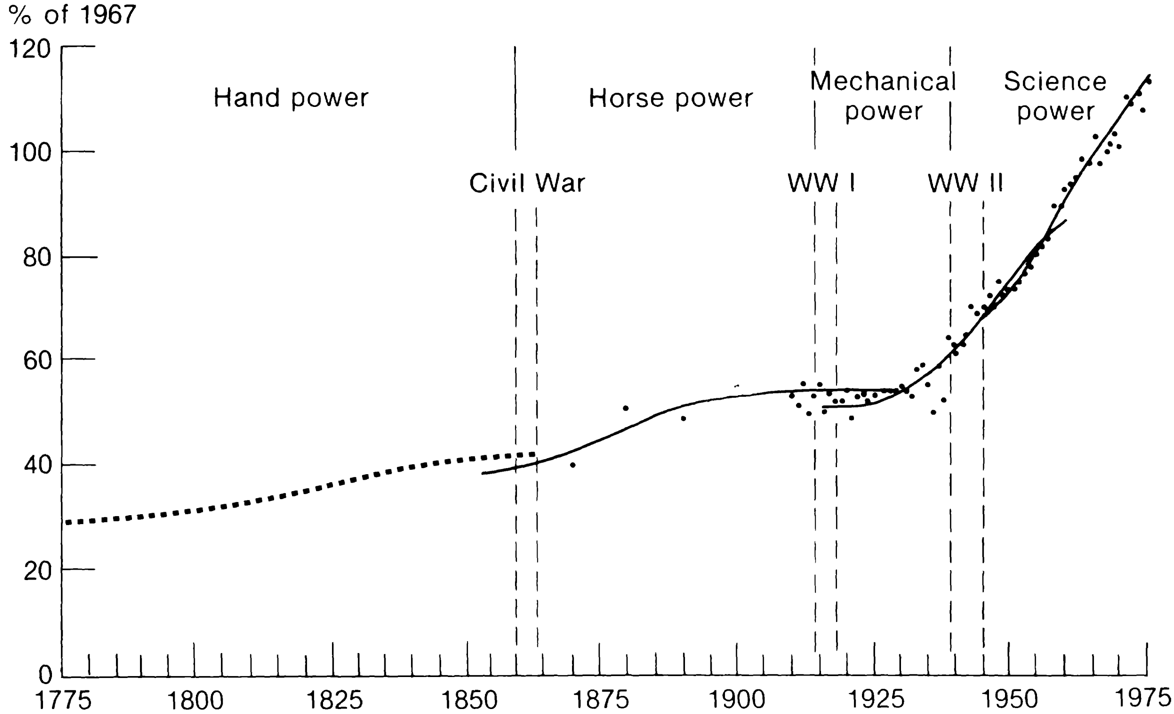
The emergence of horse power technology caused productivity growth to break through the limit imposed by hand power technology and thus shifted productivity growth to a new S-shaped curve. As illustrated in figure 2, productivity accelerated after the Civil War until about 1880 and then tapered off toward the beginning of World War I as the full potential of horse power was reached.

World War I to World War II: Mechanical Power

Although the first practical self-propelled gasoline tractor, the forerunner of the John Deere tractor, was built by John Froelich in 1892, internal combustion engine tractors were not widely adopted until the outbreak of World War I. During the war, high farm prices and high wages relative to machinery prices caused rapid conversion from horse power to mechanical power. The adoption of gasoline-powered tractors during World War I signaled the beginning of the second agricultural revolution,

Figure 2

U.S. Agricultural Productivity Growth During the Past 200 Years



but the post-World War I agricultural, and the corresponding general, depression delayed an upsurge in productivity growth until after 1935. Increasing demand fostered by general economic recovery and war in Europe accelerated the mechanization of U.S. agriculture, and by World War II the transition from horse power to mechanical power was complete. Mechanical power innovation brought productivity growth to another S-shaped curve. However, contrary to previous epochs, rather than leveling off, productivity growth accelerated because of a continuous flow of other technologies, such as chemical fertilizers, insecticides, hybrid crop varieties, and improved breeds of livestocks, into the agricultural production process.

World War II to the Present: Science Power

Mechanization was only the first phase of a phenomenal growth in agricultural productivity since World War I. Through genetic and chemical as well as mechanical engineering research, many new technologies were developed. After World War II, with widespread use of chemical fertilizers, the complementary potential for such technologies began to be realized. During this period, farmers increased crop yields through irrigation; greater use of lime, chemical fertilizers, and insecticides; widespread use of legumes and other conservation practices; and adoption of improved varieties such as hybrid corn. They adopted improved breeds, practiced artificial insemination of livestock, and increased livestock feeding efficiency. Each new technology tended to shift the productivity growth curve upward before the curve leveled off near the limit imposed by mechanical power. Because of continuing mechanization and rapid adoption of other major technological breakthroughs, productivity has continued to grow. It is during this period that society in general has begun to experience a major new information revolution and such rapid change that Toffler (*74*) has labeled it "future shock."

The complementary relationship among modern technologies has led to the recognition of technology as a resource. Unlike natural resources, technology is a man made resource whose abundance can be continuously increased through research and development (*69*). The probability of a limit to growth in agricultural productivity is thereby further reduced.

SOURCES OF PRODUCTIVITY CHANGE

Technological change is the major source of productivity change. However, to affect productivity, technology must be adopted in the production process. Extension activities, farmers' educational levels, profitability, and the availability of credit have major roles in determining the time required for the diffusion of a new technology.

Although many factors contribute to agricultural productivity growth, technology is the most important force in the longrun. Technological change has caused fundamental shifts in agricultural energy sources and provided new farm products, new capital equipment, and new production processes.

Productivity Change, Technological Change, and Technical Change

The terms, productivity change, technological change, and technical change, represent different theoretical concepts. However, in economic literature they are often used synonymously.

In this study, productivity measures the efficiency with which resources are transformed into goods and services that satisfy human wants (*20*). The productivity measure used in this study is the ratio of output to all inputs combined, that is, total factor productivity.

Technology, a special form of knowledge, involves transformation of the material environment into a flow of goods and services that satisfy human wants (*60*, p. 5). The maximum output of goods and services obtainable from every possible input combination under a given state of technology is described by a production function.

An increase in the stock of knowledge is called technological change. Technological change enables farmers to produce more output for the same quantity of inputs or the same output from a smaller quantity of inputs. Thus, a new production surface is created. If the isoquant of the new production surface is plotted on the same graph as the isoquant of the old production surface, the new isoquant will be closer to the origin.

As shown in figure 3, Q_1 represents an isoquant under old technology and Q_2 represents an isoquant under the new technology producing the same output as that of Q_1. Movement from Q_1 to Q_2 reflects the effect of technological change.

Technological change is thus the major force behind productivity change; however, productivity increases only when the stock of knowledge is incorporated into production processes.

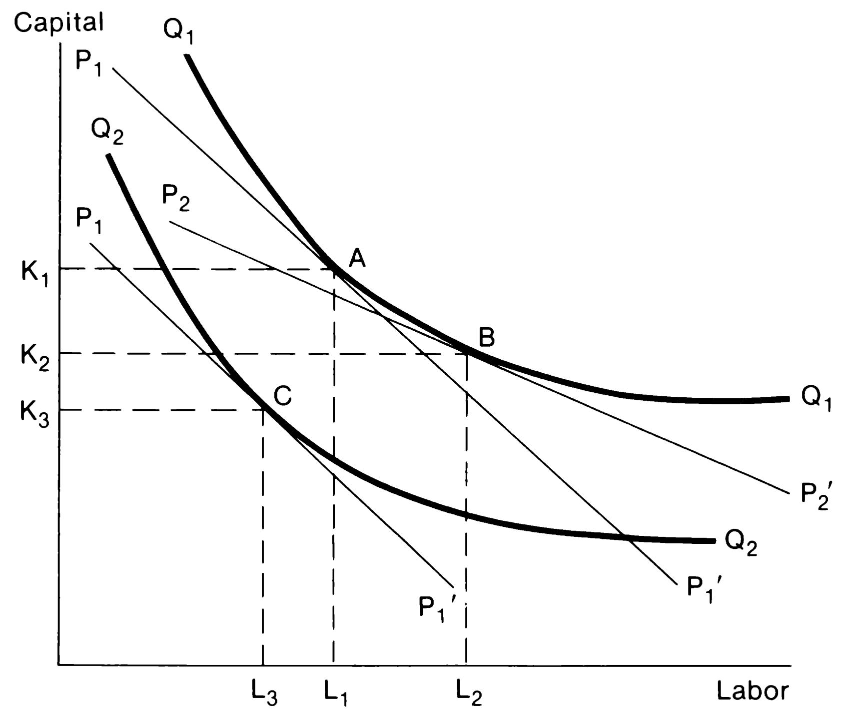
A technique, as distinguished from a technology, is a method of producing a given good or service. When a firm produces a new good or service, uses a new method, or uses a new input—regardless of whether such a good or service, method, or input is new to other firms—the firm is said to make a technical change (*65*, p. 2). A technical change can occur with or without technological change, but technological change often results in technical change. The first firm to make a given technical change is called an innovator and its action is called innovation.

These three concepts and their interrelationships can be illustrated in a production function framework. Given the state of technology described by the isoquant Q_1 in figure 3, there is a wide range of possible techniques or combinations of capital and labor that can be selected to produce the same level of output, where the land input is fixed. Some techniques require little capital and much labor; others require much capital and little labor.

Points A and B shown in figure 3 represent two different known techniques for producing the same output Q_1 under the same state of technology. Technique A requires more capital and less labor than technique B. If the relative prices of capital and labor are such that the price line is P_1P_1', technique A is adopted. Point A is the equilibrium point where a given output Q_1 can be produced with a minimum cost. When the wage rate declines, the price line changes to P_2P_2', and technique B is adopted. Thus, a change in technique from A to B is induced by a change in relative factor prices, not by technological change. A change in technique from A to B results in a change in productivity from $Q_1/(aK_1 + bL_1)$ to $Q_1/(aK_2 + bL_2)$.

Figure 3

Relationships Between Changes in Technology, Techniques, and Productivity



When a new technology is introduced, the production function shifts from Q_1 to Q_2, where both Q_1 and Q_2 represent the same amount of output. Under the new technology, the same output can be produced by using less of one or both inputs. If the relative price remains at $P_1P'_1$, technique C will be utilized and productivity will increase from $Q_1/(aK_1 + bL_1)$ to $Q_2/(aK_3 + bL_3)$, where $Q_1 = Q_2$. Therefore, productivity change occurs as a result of technical change caused by changes in relative factor prices, technological change, or a combination of both.

The Nature of Technological Change

As has been indicated, technological change causes shifts in the production function. A new production function is superior to its predecessor if less of one or more factors of production is required to produce a given output, where the input of other factors is unchanged. This process may be represented by a series of dated production functions such as Q_1 and Q_2 in figure 3.

The effect of technological change on shifts in the production function may be divided into three components: the speed of technological change, the curvature of an isoquant, and the shape of the production function (*61*).

The speed of technological change is reflected in the movement of isoquants toward the origin as new technologies appear, for example, the rate of movement from Q_1 to Q_2 over time in figure 3. This movement corresponds to the improved efficiency a new technology makes possible. The rate of movement reflects the speed of technological change.

The curvature of an isoquant represents the elasticity of substitution; it measures the ease with which one factor of production can be substituted for another, and it also measures the effectiveness of varying factor prices in changing the ratio of partial productivities. When the elasticity of substitution is zero, the isoquant curve becomes a right angle, and changes in factor prices have no effect; the factors of production are called perfect complements. When the elasticity is infinite, the curve approaches a straight line, and a slight change in factor prices can cause a complete substitution of the relatively lower cost factor for the higher cost factor; the factors are called perfect substitutes. Production factors are usually imperfect substitutes.

Changes in the shape of the curves represent biases which lead to a greater saving of one factor than another (for example, more saving of labor than capital). Such shifts tend to raise the partial productivity of one factor over another. When shifts in production functions result in savings of the same proportion of both capital and labor, such technological change is called neutral. When technological change results in greater savings of labor than of capital (such as the introduction of farm machinery), such advance is called a labor-saving technological change. If the bias is toward greater savings of capital than of labor, such technological change is called capital-saving.

Forces Underlying Productivity Growth

Productivity growth thus results from the interactions of many factors: farm policies and programs, weather, relative prices of production factors, and technology. Government farm policies and programs can work for or against productivity increases. Farm programs such as acreage retirement, target prices, and storage programs may reduce uncertainty and thereby increase productivity. Some Government regulations, such as feedlot runoff controls and bans on the use of DDT and DES, may reduce productivity.

Weather not only directly affects shortrun productivity due to fluctuating yields from year to year and longrun productivity due to weather cycles; it can also influence adoption of new technologies. A farmer in a region with relatively stable precipitation and temperature will be more willing to adopt a new technology than a farmer operating with relatively unstable weather conditions, as the former can more easily assess the costs and benefits of the new technique. The exception would be if the new technology reduced dependence on natural rainfall and temperature, as in weather modification and irrigation technologies; then the adoption pattern could be reversed.

The most important factor contributing to longrun productivity growth is technology. However, technological advance does not occur automatically. Investments in research and development are required to generate new knowledge. New knowledge may be applied by farmers directly or embodied in capital or intermediate inputs, such as pesticides (*55*).

New knowledge generated by research and development must be disseminated to, and adopted by, farmers to affect agricultural productivity. To a large extent, the rate of diffusion of a new technology is subject to profitability, degree of uncertainty, and capital requirements (*47*, p. 123).

Profitability is by far the most important determinant of the rate of diffusion. Griliches' study (*24*) indicates that hybrid corn diffused more rapidly in areas where it was more profitable than in areas where it was less so. The profitability of a new technology depends upon relative prices—that is, the prices of outputs relative to the prices of inputs and the prices of the new inputs relative to the prices of the old inputs.

Historically, relative prices have played the most important role in determining the rate of diffusion. As indicated in the section, "Historical Changes in Agricultural Productivity," many horse-drawn machines were invented before the Civil War but were not adopted because they were expensive relative to labor. The outbreak of the Civil War changed these relative prices. A war-induced labor shortage resulted in higher wages relative to the price of new machines. The relative prices of food to machines also increased as food prices rose following the disruption of production and distribution channels. Relative prices played the same role in the adoption of mechanical power during and after World War II.

Uncertainty about a new technology is another important factor in determining its diffusion. A farmer will be reluctant to adopt a new technology if he is uncertain about its payoff. The degree of uncertainty is related to the level of educational attainment of farmers and to extension activities. Extension institutions are charged to conduct programs to disseminate technical information to farmers. Increasing education and training enables farmers to better absorb, understand, and evaluate information about new products, new inputs, and new processes disseminated by USDA, extension agents, farm journals, the news media, and seed, agricultural chemical, farm machinery, and equipment companies. Therefore, increasing farmers' education and increasing extension activities will reduce uncertainty about a new technology.

Because many new technologies take the form of physical capital inputs (such as tractors) and are diffused through investments in successive generations, or "vintages" of capital goods (such as four-wheel-drive tractors), farmers must invest in more capital goods to adopt a new technology. Thus, adoption depends upon availability of credit to finance the purchase of new capital goods (*33*, p. 6).

In his study of technological change and the rate of imitation, Mansfield (*46*) concludes that the rate of diffusion of a new technology is inversely related to the size of capital investment required for its adoption. Technologies such as new hybrid varieties, fertilizer applications, or insecticides that can be tried on a small scale without committing a large capital investment are generally adopted more rapidly than grain combines or four-wheel-drive tractors which require a large capital investment.

RESEARCH, EXTENSION, AND AGRICULTURAL PRODUCTIVITY

This section develops a theoretical model for productivity projections. Agricultural productivity is assumed to be a function of the lagged effects of production-oriented research and extension (R & E) expenditures, the educational level of farmers, and the weather index.

The impact of a new technology on agricultural productivity follows an S-shaped growth curve because of the lengthy leadtime in research and development, a lag period for adoption (whose actual length depends on extension activities) by farmers, and the eventual decline in the technology's usefulness. Because research and extension complement each other in their contribution to productivity growth, we have combined them into a single variable which we then use to formulate models for agricultural productivity projections.

As previously indicated, numerous factors contribute to productivity change. To abstract from the real world and to construct a model describing the real world relationships in a simplified form, we have included only the most important, observable, and measurable variables in the model.

Although important, farm programs and relative prices have been excluded from this study. We have not yet been able to separate the price effect from the impact of technological change. Past attempts to measure the effect of farm programs on agricultural productivity have not been successful, primarily because of measurement and data problems. As relevant data on private research expenditures were unavailable, they have also been excluded from this study. Therefore, agricultural productivity is a function of lagged values of production-oriented public agricultural research and extension (R & E) expenditures, improvement in farmers' education, and weather.

Productivity Projection Model

Based on the above observations, the productivity projection model is specified as:

$$P_t = f(T_t, E_t, W_t) \qquad (10)$$

and

$$T_t = g(K_t, D_t)$$

where P_t = the aggregate productivity index for U.S. agriculture in year t,

T_t = the level of technological innovation in year t,

E_t = the index of educational attainment of farmers in year t,

W_t = the value of a U.S. weather index in year t,

K_t = the stock of knowledge in year t,

D_t = the rate of diffusion in year t.

The rate of innovation depends largely on the production of new technology through research and on its diffusion through extension. Until the new technology is used in production, it has no effect on productivity. As previously indicated, there is a lengthy lag between the creation of new knowledge (or invention) and its diffusion (or innovation). To construct a model to simulate productivity change, one needs to understand the process of technological innovation.

The Process of Technological Innovation

The process of technological innovation starts with an idea or confrontation of a problem and ends with diffusion of the corresponding technology throughout an industry or market (*4*). Bright (7) divides this process into eight stages. Because agricultural research differs from that in other industries, we modify Bright's stages as follows:

Stage 1—Initiation of an Idea

An idea may emerge in one of the following ways: (1) scientific suggestions, (2) scientific discoveries, or (3) recognition of needs or opportunities.

In searching for new knowledge, scientists may formulate new hypotheses which suggest researchable projects.

An idea may also arise from the discovery of a new product, phenomenon, or a new process during research activities. For example, the idea of developing nylon was suggested by the discovery of unusually flexible and strong fibers during research on condensation polymers at DuPont in 1928 (*45*, p. 49). Although the fibers of the original superpolymer were not of commercial value because they were easily softened by hot water, this discovery suggested that some related compound might possess suitable characteristics for manufacturing purposes. Further research was then undertaken by DuPont.

New technologies are also created as the result of needs and opportunities. The obvious example is the recent energy shortage which has prompted a multitude of energy-related research projects.

Stage 2—Proposal of a Theory

After an idea is initiated and the problem is conceptualized, a theory is proposed to solve the problem.

Stage 3—Verification

Experiments are conducted to confirm the validity of the proposed theory.

Stage 4—Laboratory Demonstration of Applications

The first primitive model of the technology is tested in the laboratory.

Stage 5—Field Trials

After laboratory tests, the new technology is tried under field conditions.

Stage 6—Commercial Introduction

The technology, believed to be ready for commercial application, is introduced.

Stage 7—Widespread Adoption

The technology is widely adopted throughout the industry or, in the case of a new product, the market.

Stage 8—Depreciation

A technology tends to depreciate after a period of time. Because most agricultural technologies are related to crops or livestock, the technology may depreciate due to biological decay (for example, insects build up resistance to certain insecticides over time) or become obsolete due to changes in relative input prices or to the introduction of other new technologies (*18*, p. 25).

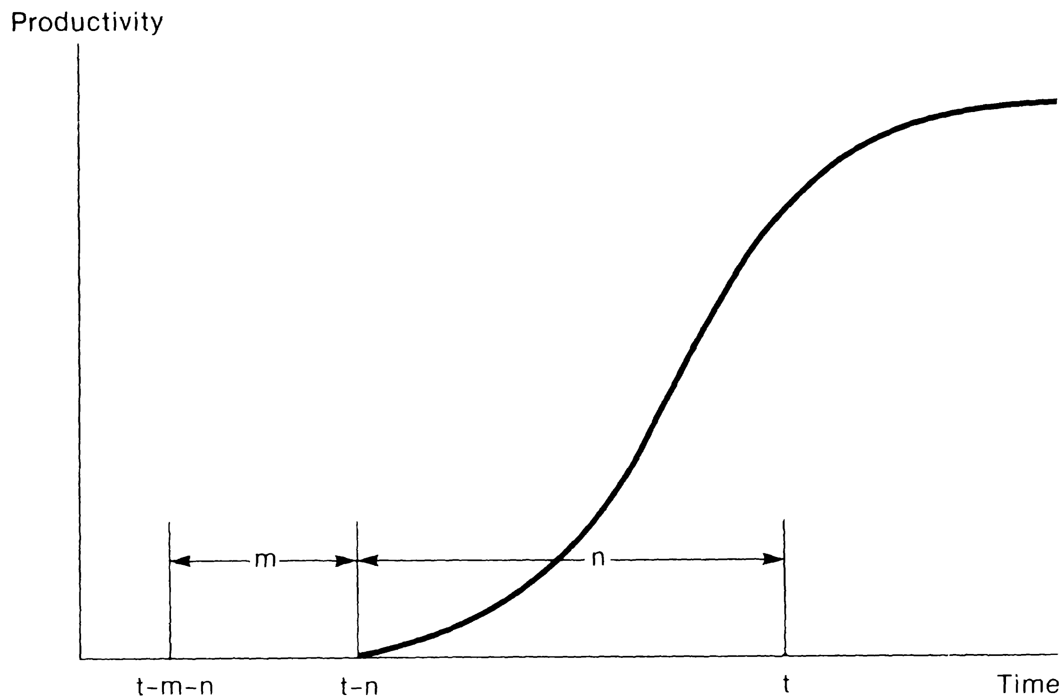
Impacts of Technological Innovation on Productivity

According to its impact on productivity, the process of technological innovation can be grouped into two periods—stages 1 through 5 and stages 6 through 8. During the first period, research resources are committed but no new technologies are created. The lag between initiation of an idea and creation of a new technology (or invention) is called leadtime. As shown in figure 4, from the time research resources are committed at time t–m–n to completion of research at t–n, no extendable knowledge is created. Consequently, the new technology in the embryo stage has no impact on productivity. The length of the leadtime varies among different research projects, ranging from a few months to years or even decades. To some extent, the length can be shortened by increased research resources.

At time t-n, the research is completed, the new technology is ready for commercial adoption, and the extension phase begins. Extension agents will conduct demonstrations and

Figure 4

The Impact of Research and Extension on Agricultural Productivity Growth



field observations to prove the new technology's profitability. As early adopters benefit from its use, more and more farmers will be attracted to it. Thus, its impact increases exponentially over time as shown in figure 4. After the maximum impact has been reached, the impact of the new technology on productivity will begin to decline due to depreciation.

The time between stages 6 and 7 is called an adoption lag. The lag length varies with different technologies. In his study of adoption lags of 23 machines, Jerome (*28*) indicates that the typical duration for commercial trial is 3 to 11 years; rapid increase in use, 4 to 11 years; slackened increase (with an annual gain of less than 10 percent), 3 to 6 years; and decline, an undefined period.

In agriculture, the length of adoption lags has ranged from 3 years for DDT to 53 years for cotton pickers (*45*, p. 101). The rate of adoption of a given technology also varies with different places. In studying the diffusion of hybrid corn, Griliches (24) indicates that Alabama took 8 years to increase its adoption rate from 20 to 80 percent, but Iowa took only 3 years to reach the same stage of adoption. For all States, regardless of lag length, the growth of the percentage of users had an S-shaped curve (*45*, p. 119).

Although the length of adoption lag may vary, the shape of the adoption profile tends to follow an S-shaped growth curve. As the impact of a new technology on productivity is proportionate to the adoption rate, the impact of a new technology on productivity also follows an S-shaped growth curve.

Theoretical Model

From these relationships, it is evident that when research resources are committed from time t–m–n to t–n, no new knowledge is forthcoming. At t–n, the research is completed and new knowledge is available. The stock of knowledge (K) depends upon research resources committed during the period t–m–n through t–n as follows:

$$K_{t-n} = h\,(S_{t-n}, S_{t-n-1}, \ldots, S_{t-n-m})$$

where S's are research resources committed.

At t–n, the diffusion of new technology begins and extension activities come into play. With a given level of technology, the more active the extension activities are, the faster the adoption will be and, therefore, the higher the impact on productivity will be. Thus, the level of technological innovation in year t is:

$$T_t = g(K_t; X_t, X_{t-1}, ..., X_{t-n}) \qquad (11)$$
$$= g(S_{t-n}, ..., S_{t-m-n}; X_t, ..., X_{t-n})$$

where X's are resources committed to extension activities and the stock of knowledge created in t–n is assumed to remain the same in t. Substituting equation (11) into equation (10) yields:

$$P_t = f(S_{t-n}, ..., S_{t-m-n}; X_t, ..., X_{t-n}; E_t; W_t) \qquad (12)$$

These observations suggest that research and extension complement each other to raise productivity.

Although in the above equation, it was more desirable to estimate the separate effects of research and extension, this study combines research and extension into a single variable for three reasons. First, because of their complementary relationship, research and extension contribute jointly to productivity increases. Second, extension contributes to improving labor quality and management in much the same way that research does. Finally, time series data of research and extension are highly correlated. High multicollinearity prevents estimating the separate contribution of research and extension (*18*, p. 43).

Combining Research and Extension

Although research and extension contribute jointly to productivity growth, they enter into the process of technological innovation at different times. As shown in figure 4, extension activities lag behind research activities by m years. Consequently, research can be combined with extension by lagging m years if the lag is known.

However, the above simplified model does not perfectly depict the process of technological innovation in agriculture. Historically, the leadtime for major technological breakthroughs has been lengthy, and even before the completion of the research, impacts on agricultural productivity are emerging. Rosenberg (*59*, p. 76) expresses the same view:

> Innovation is, economically speaking, not a single well-defined act but a series of acts closely linked to the inventive process. An innovation acquires economic significance only through an extensive process of redesign, modification, and a thousand small improvements which suit it for a mass market, for production by drastically new mass production techniques, and by the eventual availability of a whole range of complementary activities, ranging, in the case of the automobile, from a network of service stations to an extensive system of paved roads.

That is, a single technological breakthrough may represent many minor technologies developed over a period of years. For example, the first substantial commercial-scale application of research results on hybrid corn did not occur until the thirties, although serious research on hybrid corn began early in the century (*47*, p. 122). In 1906, G.H. Shull, a geneticist at Cold Spring Harbor, New York, started experiments on heredity in corn (*68*, p. 106). Many State and Federal inbreeding and hybridization programs were started in the early twenties. By 1921, the first commercial, double-cross hybrid, Burr-Leaming, was released and recommended by the Connecticut agricultural experiment station. Hybrid corn technology has involved almost continuous developments of new hybrids. Thus, there has been a considerable overlapping of leadtime and adoption lag.

Each year the public sector finances a large number of research activities. Because leadtime for minor technologies is usually short and major technological breakthroughs continuously "release" small technologies, there are always some extendable technologies in any given year. One may assume that research activities in a given year will produce some technologies which can be disseminated the following year. Therefore, we combined research expenditures in the previous year with extension expenditures in the current year.

If research and extension are combined into a single variable, equation (12) can be rewritten as:

$$P_t = f(R_t, R_{t-1}, ..., R_{t-n}; E_t; W_t) \qquad (13)$$

where the R's are combinations of research and extension expenditures.

ESTIMATION PROCEDURES

This section reviews the data sources for national and regional indexes of agricultural productivity and for the three independent variables—the educational attainment of farmers, weather, and public expenditures in agricultural research and extension (R & E). It specifies a model, which includes the three independent variables, for projecting agricultural productivity.

The Almon polynomial lag technique and the Durbin two-stage procedure are used to estimate the parameter of the model.

Data Sources

Time series data used in this study were derived from many different sources, which are only briefly summarized here. For a more detailed description of the sources and for the method used to construct the time series data, see Cline (*11*).

The productivity index is measured by total farm output per unit of input. Regional and national productivity data for 1939-72 are from the 1964 and 1973 issues of *Changes in Farm Production and Efficiency*.[6]

The farmers' educational attainment index for the United States updates a series reported by Evenson (*18*). Regional indexes were constructed from the national index and from the relative educational positions of the farm production regions in 1970; it was assumed that the trend for educational attainment has been the same across these regions over time.

The weather index for the United States for 1900-49 was obtained from Stallings (*71*) and was updated by Kost (*36*) for 1950-63. The index for 1964-72 was constructed from crop yield data; variations in crop yields from the trend were assumed to be attributable to weather.

The Stallings index of the influence of weather on aggregate farm output was obtained from the weighted average of weather indexes for individual crops, where production values for each crop during 1967-69 were used as weights. For individual crops located in more concentrated production areas, weather indexes were computed from time series of experimental plot data. A linear regression line was fitted to the time series data. The weather index for each crop was computed from the ratio of actual yield to computed yield from the regression. Kost used the same procedure to update the weather index for 1950-63.

Regional indexes were constructed by using basically the same procedure as that employed for obtaining national indexes for 1964-72. A weather index value of 100 indicates "normal" weather; that is, the long-term average weather condition. The average weather index for 1900-72 is 100.7, indicating that the average weather during this period was slightly above normal—a result that agrees with many climatologists' observations.

Production-oriented and nonproduction-oriented R & E expenditures were derived and constructed from public sector expenditures on agricultural R & E. The total expenditures series for the Agricultural Research Service (ARS), now part of USDA's Science and Education Administration (SEA), was compiled from actual outlays on a checks-issued basis as reported annually in the *Combined Statement of Receipts. Expenditures and Balances of the United States Government*. Production-oriented expenditures were isolated from nonproduction-oriented expenditures by using information from the annual *Budget of the United States Government*, which contains a functional breakdown of appropriations by activity. ARS regional expenditures were constructed under the assumption that the regional share of USDA's research conducted within State Experiment Stations adequately reflects the regional distribution of total ARS expenditures.

Data for the Economic Research Service

[6] U.S. productivity data for 1910-76 and regional data for 1939-76 are now available in the 1977 issue of *Changes in Farm Production and Efficiency*, U.S. Dept. Agr., Econ. Res. Serv., Stat. Bull. No. 581.

(ERS), now part of the USDA's Economics, Statistics, and Cooperatives Service (ESCS) production-oriented and nonproduction-oriented expenditures for the 1939-72 period were obtained from essentially the same sources as those for the ARS series. ERS regional expenditures were constructed using the same assumption as for ARS.

Data on total experiment station expenditures are from *Funds for Research at State Agricultural Experiment Stations and Other State Institutions.* This information is available at the State level, which allows aggregation to the regional level. The production-oriented expenditures of the experiment stations were assumed to equal their total expenditures. (This assumption was based upon data provided by a small sample of "typical" experiment stations, where production-oriented expenditures in 1970-73 amounted to more than 98 percent of total expenditures.)

Data on total Extension Service (ES), now part of the Science and Education Administration, expenditures are from published and unpublished *Annual Reports of Cooperative Extension Work in Agriculture.* These data were also available on a State basis, which allows regional aggregations. To isolate production-oriented expenditures, we weighted ES total expenditures by the percentage of total extension workers' total time devoted to agricultural production activities. The distributions of extension workers' time by activity for 1929-62 were obtained from *Extension Activities and Accomplishments.* Observations for 1964, 1968, 1969, and 1973 were obtained from unpublished ES work sheets. Remaining observations were obtained by linear extrapolation.

Data on expenditures of the Soil Conservation Service (SCS) for soil conservation operations for 1936-61 were obtained from Latimer (*38*). Latimer reports these data by State, which allows regional aggregations. Observations for 1962-72 are from the *Budget of the United States Government* and represent funds obligated for soil conservation operations; they may differ slightly from actual expenditures.

The portion of total expenditures that each USDA agency spent on scientific personnel is deflated by an index of average salaries of college and university teachers. For 1929-49, these figures are reported by Stigler (*70*). Salary information published in the *AAUP Bulletin* was used to update the Stigler index.

The residual portion of total research and extension expenditures was deflated by the implicit price deflator for Government purchases of goods and services.

Estimation Methods

Based on the preceding information, we can now specify a productivity model as follows:

$$P_t = \prod_{i=0}^{n} R_{t-i}^{\alpha_i} O_t^{\delta} E_t^{\beta} e^{\gamma W_t} \qquad (14)$$

where:

P_t = the aggregate productivity index for U.S. agriculture in year t,

R_{t-i} = the lagged values of production-oriented R & E expenditures, measured in thousands of 1958 dollars.

O_t = the current value of nonproduction-oriented research and extension expenditures, which are related to nonproduction-oriented R & E activities (such as child development, community development, health, food preparation and selection, and marketing and utilization of farm products), measured in thousands of 1958 dollars.

E_t = the index of educational level of farmers in the current period.

W_t = the weather index in the current period.

n = the length of lag measured in years.

$\alpha, \beta, \gamma, \delta$ = parameters.

Equation (14) indicates that the level of productivity in the current year is a function of the current educational level of farmers, weather conditions, and a distributed lag function of research and extension expenditures. It is hypothesized that the form of the distributed lag weights follows an inverted U shape.

To estimate the parameters, equation (14) is transformed to the following logarithmic form:

$$\ln P_t = \sum_{i=0}^{n} \alpha_i \ln R_{t-i} + \delta \ln O_t + \beta \ln E_t + \gamma W_t + u_t \qquad (15)$$

where u_t is the disburbance term. The parameters of equation (15) could be estimated directly using the ordinary least squares procedure. However, the length of lags is unknown, and the R variables are likely to be highly correlated. To overcome this difficulty, several approaches have been suggested: the Koyck (*37*) model, the Pascal (*66*) distribution, the Jorgenson (*30*) rational lag approach, the de Leeuw (*15*) "inverted V" approach, and the Almon (*2*) polynomial lag technique.[7]

A priori information about the time form of the distributed lag weights derived from the theory advanced in the section, "Research, Extension, and Agricultural Productivity," suggests that the Almon polynomial lag technique is appropriate for estimating the weights of R & E variables. This technique is based on the theorem that the weights of the distributed lag model (15) lie on a polynomial of degree p. It is assumed that there exist parameters $a_0, a_1, ..., a_p$ such that:

$$w_i = a_0 + a_1 i + a_2 i^2 + ... + a_p i^p,$$
$$i = 0,1,...,n; \; p \leq n$$

This procedure reduces the number of parameters from n+1 $(w_0, w_1, ..., w_n)$ to p+1 $(a_0, a_1, ..., a_p)$ by imposing a restriction that the weights of the distributed lag variables follow a polynomial of degree p. As with any *a priori* restriction, requiring the weights to lie on a polynomial will result in unbiased, consistent, and more efficient estimates than the ordinary least squares estimates—if the restriction is true. If the restriction is not true, such an imposition will lead to biased and inconsistent estimates and to invalid tests (*64*). Therefore, before applying the Almon technique, one should have *a priori* information that the restriction is true. From the theoretical consideration of the nature of these lags, it would appear that there are distributed lags in the effects of research and extension and that the weights of these lags can be traced with a polynomial function, even though their length and the degree of polynomial are not known.

In applying the Almon technique, the length of lags (n) and the degree of polynomial (p) must be simultaneously inferred. Without *a priori* information, a number of different lag lengths and varying degrees of polynomial can be tried, and the "best" lag length and degree of polynomial can be selected by using the theory and statistical criteria.

In applying the polynomial lag technique, Almon suggests that "endpoint" constraints (that is, $w_{-1}=0$ and $w_{n+1}=0$) should be imposed. However, as with other *a priori* constraints, imposing endpoint constraints will increase the efficiency of estimation if the constraints are justified but will lead to biased and inconsistent estimation if they are unjustified (*76*). Therefore, the endpoint constraints should not be applied unless there is a good reason to believe they are valid. Without *a priori* information on the appropriateness of endpoints, Schmidt and Waud (*64*, p. 13) suggest that the equation should be estimated both with and without constraints so that the appropriateness of imposing constraints can be tested using an explicit statistical criterion, such as the standard F test. This procedure is followed in this study.

Statistical Problems

In estimating equation (15) using the original data, we face two common statistical problems: multicollinearity and autocorrelation. To measure the degree of multicollinearity, the simple correlation coefficients between independent variables have been computed. Except for the weather variables which exhibit low correlation with all other independent variables, the correlation coefficients between all other pairs of independent variables are very high, ranging from 0.924 to 0.972.[8] Each independent variable was regressed on the remaining independent variables to determine the linear dependence among them. As expected, the coefficients of determination were high, ranging from 0.919 to 0.977. Both tests indicate the existence of a high degree of multicollinearity in the original data, which can result in imprecise estimates.

To test the presence of autocorrelation, the Durbin-Watson "d" statistic was used. Using the Almon polynomial lag technique, we fitted equation (15) to the data. Polynomials of degrees 2 and 3 with lag lengths ranging from 3 to 24 years were tried. The Durbin-Watson tests were inconclusive in most cases. In instances where the tests were not inconclusive, the null hypothesis of nonautocorrelated disturbances was rejected at the 5-percent significance level.

Because of autocorrelated disturbances, equation (15) was transformed into the following

[7] For a survey of literature on distributed lags, see Griliches (*22*).

[8] For more detailed test results than those reported in this section, see Cline (11).

form, with the assumption that the disturbance term u_t follows a first-order autoregressive scheme.

$$\ln P_t - \rho \ln P_{t-1} = \sum_{i=0}^{n} \alpha_i (\ln R_{t-i} - \rho \ln R_{t-i-1}) + \delta (\ln O_t - \rho \ln O_{t-1}) + \beta (\ln E_t - \rho \ln E_{t-1}) + \gamma (W_t - \rho W_{t-1}) + e_t \quad (16)$$

where: $e_t = u_t - \rho u_{t-1}$.

To overcome the multicollinearity problem, some researchers transform the time series data to first differences. Under some circumstances, this transformation may reduce the degree of multicollinearity (*35*, p. 390). As the first difference model, where the first-order autocorrelation coefficient is equal to one, is a special case of the first-order autocorrelated model, we used the first-order autocorrelated model to solve both autocorrelation and multicollinearity problems.

We employed Durbin's (*17*) two-stage procedure to estimate the autocorrelation coefficient. We estimated equation (16) with polynomials of degrees 2, 3, and 4—both with and without imposition of the endpoint constraints. Lag lengths for research and extension expenditures were allowed to vary from 7 to 16 years.

Results indicated that the third- and fourth-degree polynomials yield weights which oscillate in sign. This characteristic is not consistent with the theory. On the other hand, results obtained from using the second-degree polynomial not only conform with the theory but also give lower standard errors of estimates. Thus, the second-degree polynomial was selected for the final estimation.

In the process of estimation, the coefficient of nonproduction-oriented R & E expenditures was not significantly different from zero even at the 15-percent level. Therefore, the variable was dropped from equation (16) in the final estimation.

To determine the appropriateness of imposing endpoint constraints, equation (16) was estimated both with and without constraints. The null hypothesis that the endpoints are zero was tested by the F statistic:

$$F_{m,m-k} = \frac{(e'e - e_1'e_1)/n}{e_1'e_1/(n-k)}$$

where $e'e$ is the residual sum of squares calculated from the restricted model, $e_1'e_1$ is the residual sum of squares obtained from the unrestricted model, m is the number of endpoint constraints, n is the number of observations, and k is the number of independent variables.

For the lag length of 13 years in the U.S. data, the calculated F value is 0.085, which is far below the table value of F distribution at the 1-percent level. Thus, the null hypothesis that the endpoints are equal to zero is not rejected. Furthermore, for every lag length, the standard error of estimates obtained from the restricted model was lower than that for the unrestricted model. For example, for the lag length of 13 years in the U.S. data, the standard error of estimates from the restricted model is 0.0204, whereas the same statistic from the unrestricted model is 0.0211. These results combined with the F test indicate that the imposition of endpoint constraints is justified.

With the nonproduction-oriented R & E variable excluded, equation (16) was estimated with the constraint that the endpoints equal zero. Lag lengths were allowed to vary from 7 to 16. Results indicated that the autocorrelation coefficients ranged from 0.52 to 0.65 and, in most cases, the Durbin-Watson tests did not reject the null hypothesis of no autocorrelated disturbances. In the remaining cases, the tests were inconclusive.

The first-order autocorrelated model not only alleviates the autocorrelation problem but also reduces the degree of multicollinearity. The coefficients of determination between each independent variable and the remaining variables are reduced from 0.919–0.977 in the original model to 0.468–0.655 in the autocorrelated model. Furthermore, the regression coefficients across different data sets associated with different lag lengths become very stable. The reduction in the coefficients of determination combined with the stability of the regression coefficients indicate that the degree of multicollinearity is reduced.

EMPIRICAL RESULTS

The effect of the agricultural research and extension (R & E) investment on agricultural productivity lasts an average of 13 years at the national level. This lag length was selected through the statistical criterion of standard error of estimate. Lag lengths of agricultural R & E expenditures differ significantly among regions, ranging from 9 years in the Pacific to 14 years in the Lake States.

An annual 1-percent increase ($3.8 million in 1972) in production-oriented R & E expenditures at the national level will increase agricultural productivity 0.037 percent, a seemingly small amount but one that represents a significant growth in the actual dollar value ($13 million) of increased farm output. If the overall educational level of farmers is raised by 1 month (that is, an annual increase in the education index of approximately 1 percent), the value of net farm output will increase approximately $267 million (1958 dollars).

Estimates from U.S. Data

Equation (16) was fitted to the U.S. and regional data by using the Almon distributed lag technique and the Durbin two-stage procedure. Following the procedure described in the previous section, the quadratic form was selected to fit the weights of the distributed lags (table 1). The lag length was allowed to vary from 7 to 16 years, and in all cases endpoint constraints were imposed.

Two statistical criteria can be used to select the "best" lag length: the coefficient of multiple determination adjusted for the number of degrees of freedom ($\bar{R}^2$) and the standard error of estimate.[9] Differences in the coefficients of determination associated with varying lag lengths are too small to provide a basis for selection; they all exceed 0.999. Therefore, the second criterion was selected. The standard error of estimate declines as the lag length increases, reaches a minimum of 0.02036 when the lag is 13 years, and rises again as it increases. Therefore, 13 years is selected as the optimal lag length.

The Durbin-Watson statistics associated with different lag lengths vary little, but they all exceed the upper bound of the table value. Therefore, the null hypothesis of random disturbances is accepted at the 1-percent level of significance.

The estimated regression coefficients are relatively stable across different lag lengths. The regression coefficients of the education variable, for example, vary from 0.7299 to 0.8393, whereas the coefficients of the weather variable vary from 0.0018 to 0.0021. The coefficients of the lagged R & E variables show similar stability.

Coefficients of the educational variable for all lag lengths differ significantly from zero at the 1-percent level. In the 13-year lag, the regression coefficient is 0.78, which implies that a 1-percent increase in the educational level of farmers will raise agricultural productivity 0.78 percent.

To translate the impact of increased education among farmers on agricultural productivity into concrete terms, let us consider the year 1970. The average number of years of schooling for farm operators, laborers, and foremen is 9.12, and the computed education index is 157.2. An index point of 1.0 is equivalent to 0.058 year, or about 0.7 months of schooling. Thus, a 1-percent increase in the education index is equivalent to about 1 month of education (0.7 × 1.572). Therefore, if the overall level of education of farmers is raised by 1 month, the value of net farm output will increase about $267 million (1.0 index point

[9] The standard error of estimate is defined as the positive square root of the ratio of the error sum of squares to the number of degrees of freedom.

Table 1 — Estimates of distributed lag equation for U.S. agriculture

Variables	Lag length (years)									
	7	8	9	10	11	12	13	14	15	16
Education	0.8387 (4.9936)	0.8340 (4.5962)	0.8393 (4.2950)	0.8209 (3.9249)	0.7856 (3.1705)	0.7663 (3.2118)	0.7851 (3.0440)	0.7501 (2.8138)	0.7493 (2.6632)	0.7299 (2.5554)
Weather	.0018 (4.0466)	.0018 (4.0744)	.0018 (4.0980)	.0018 (4.1122)	.0019 (4.3277)	.0021 (4.7306)	.0020 (4.7337)	.0020 (4.4566)	.0020 (4.3708)	.0020 (4.3906)
Distributed lag weights in years:										
0	.0012	.0011	.0008	.0006	.0013	.0013	.0009	.0011	.0010	.0010
1	.0021	.0019	.0014	.0017	.0023	.0023	.0017	.0021	.0019	.0020
2	.0027	.0025	.0019	.0023	.0031	.0032	.0024	.0030	.0027	.0028
3	.0030	.0029	.0022	.0028	.0038	.0039	.0029	.0036	.0033	.0034
4	.0030	.0030	.0024	.0030	.0042	.0043	.0033	.0042	.0038	.0040
5	.0027	.0029	.0024	.0031	.0044	.0046	.0036	.0045	.0042	.0044
6	.0021	.0025	.0022	.0030	.0044	.0047	.0037	.0048	.0045	.0047
7	.0012	.0019	.0019	.0028	.0042	.0046	.0037	.0049	.0046	.0049
8		.0011	.0014	.0023	.0038	.0043	.0036	.0048	.0046	.0050
9			.0008	.0017	.0031	.0039	.0033	.0045	.0045	.0049
10				.0006	.0023	.0032	.0029	.0042	.0042	.0047
11					.0013	.0023	.0024	.0036	.0038	.0044
12						.0013	.0017	.0030	.0033	.0040
13							.0009	.0021	.0027	.0034
14								.0011	.0019	.0028
15									.0010	.0020
16										.0010
Sum of weights	.0177	.0196	.0175	.0249	.0381	.0438	.0369	.0515	.0519	.0595
$\bar{R}^2$	[1].9990	[1].9990	[1].9990	[1].9990	[1].9990	[1].9990	[1].9990	[1].9990	[1].9990	[1].9990
Standard error of estimate	.0219	.0219	.0219	.0218	.0218	.0211	.0203	.0206	.0210	.0211
Durbin-Watson statistics	[2]2.2500	[2]2.2700	[2]2.3100	[2]2:3400	[2]2.3900	[2]2.1400	[2]2.2900	[2]2.3000	[2]2.2900	[2]2.2000
Autocorrelation coefficient	[1].7290	[1].7350	[1].7450	[1].7560	[1].8190	[1].7950	[1].8390 [1]	[1].8300	[1].8300	[1].8190

Numbers in parentheses are t-values.
[1] Fourth zero after decimal point was added after rounding.
[2] Third and fourth zeros after decimal point were added after rounding.

equals approximately $343 million in 1958 dollars).

Regression coefficients of the weather variable are positive and significant at the 1-percent level for all lag lengths. A 1-percent increase in the weather index will raise productivity 0.002 times W percent. Under normal weather where W = 100, productivity is expected to increase 0.2 percent in response to a 1-percent increase in the weather index.

To test the significiance of the regression coefficients for lagged R & E variables, we conducted a joint F test of the null hypothesis that all coefficients for lagged R & E variables are equal to zero. Results indicate that the null hypotheses were rejected for all lag lengths at the 1-percent level of significance.

For a lag length of 13 years, the distributed lag coefficients imply that a 1-percent increase in production-oriented R & E expenditures will increase agricultural productivity only 0.0009 percent for the first year, but the impact will increase gradually during subsequent years until a peak of 0.0037 percent is reached in the sixth and the seventh years. Then the impact will decline gradually, as shown in figure 5. The sum of lag coefficients, 0.037, suggests that a 1-percent increase in production-oriented R & E expenditures will increase agricultural productivity 0.037 percent over a 13-year period.

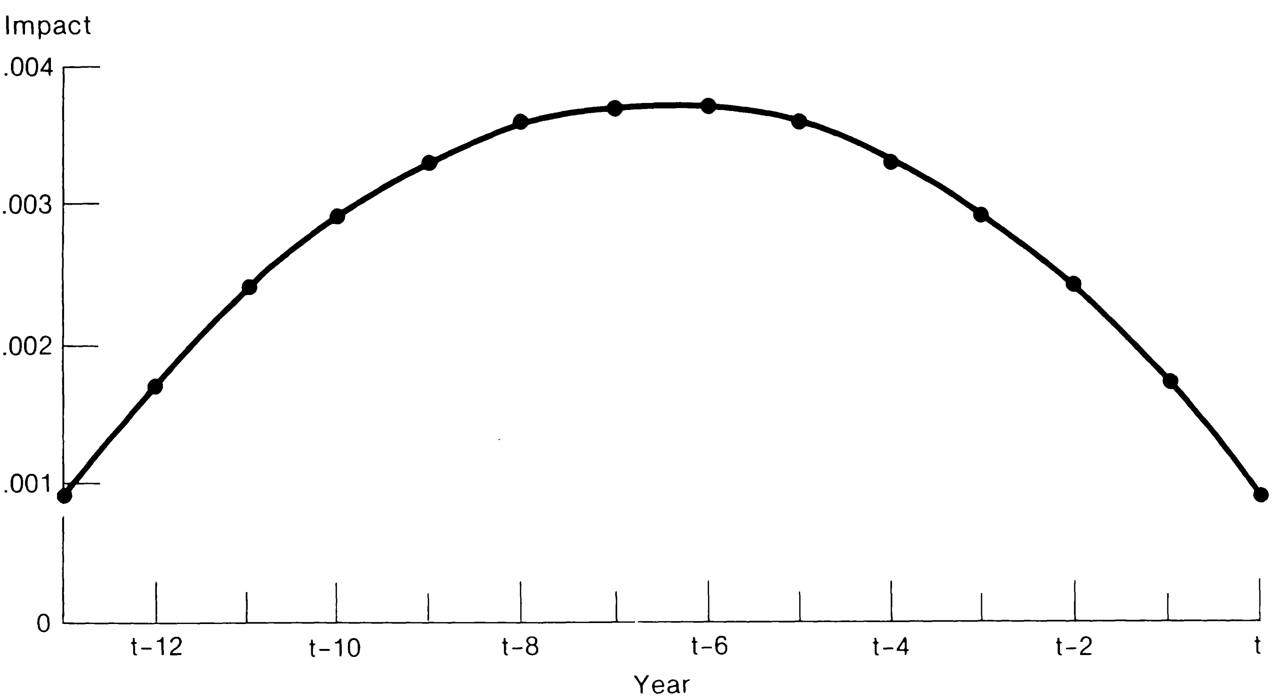
The impact of R & E on productivity may seem rather small; however, the implied effect in terms of the dollar value of increased farm output is quite significant. For example, the production-oriented R & E expenditure in 1972 was $377 million (in 1958 constant dollars). One percent of R & E expenditures is $3.8 million. However, a 0.037-percent increase in agricultural productivity is worth about $13 million, although to be comparable with present costs, future returns have to be discounted. (More detailed analyses of returns to R & E will be discussed in the next section).

Estimates from Regional Data

The procedure used in the preceding section was also applied to the data for each of the 10 farm production regions. However, because of high collinearity between the R & E variable and the education variable and the resulting large sample variances of the estimated coefficients,

Figure 5

Impact of Research and Extension on U.S. Agricultural Productivity



the estimated regression coefficients were unstable and inaccurate.

To overcome this difficulty, extraneous information was brought into the estimation. The estimated coefficient of the education variable in the U.S. data was substituted for the coefficient of the education variable in the regional models. The regression equation fitted to the regional data then becomes:

$$\ln P_t - \hat{\rho} \ln P_{t-1} - 0.78 (\ln E_t - \hat{\rho} \ln E_{t-1}) \quad (17)$$
$$= \sum_{i=0}^{n} \alpha_i (\ln R_{t-i} - \hat{\rho} \ln R_{t-i-1})$$
$$+ \gamma (W_t - \hat{\rho} W_{t-1}) + e_t$$

where 0.78 is the estimated coefficient of the education variable from the U.S. data. The Almon distributed lag technique and the Durbin two-stage procedures were used to estimate equation (17). For all regions, the quadratic form was used to fit the distributed lag weights, the endpoints were constrained to zero, and the lag length of the R & E variable was allowed to vary from 8 to 17 years. Again, the minimum standard error of estimate was used to select the optimal lag lengths for each region (table 2 and fig. 6).

The Durbin-Watson statistics indicate that the null hypotheses of random disturbance, when tested against the alternative hypothesis of positive autocorrelation, were accepted for all regions except the Corn Belt, the Southern Plains, the Mountain, and the Pacific regions. For those regions, tests were inconclusive.

For all regions, except the Pacific region, the adjusted coefficients of determination exceeded 0.9, and all the regression coefficients of the weather variable were positive and significantly different from zero at the 1-percent level. For each region, the null hypothesis that all coefficients of the lagged R & E variables were equal to zero was rejected at the 1-percent level of signficiance by the joint F tests.

Lag lengths of R & E expenditures differ significantly among regions, ranging from 9 years in the Pacific to 14 years in the Lake States (table 2). Regional differences can be attributed to differences in R & E investment per unit of output, the educational level of farmers, weather conditions, and the crop/livestock ratio.

Cline (*11*) hypothesized that the greater the production-oriented R & E expenditures per dollar value of output, the shorter the lag length; the greater the weather variability in the region, the longer the lag length; the better the absolute weather conditions as measured by the weather index, the shorter the lag length; and the higher the ratio of crop output to livestock output in the region, the shorter the lag length. He tested these hypotheses using Kendall's rank correlation. The results support all these hypotheses except the one related to weather variability.

Figure 6

Impact of Research and Extension on Agricultural Productivity for Ten Farm Production Regions

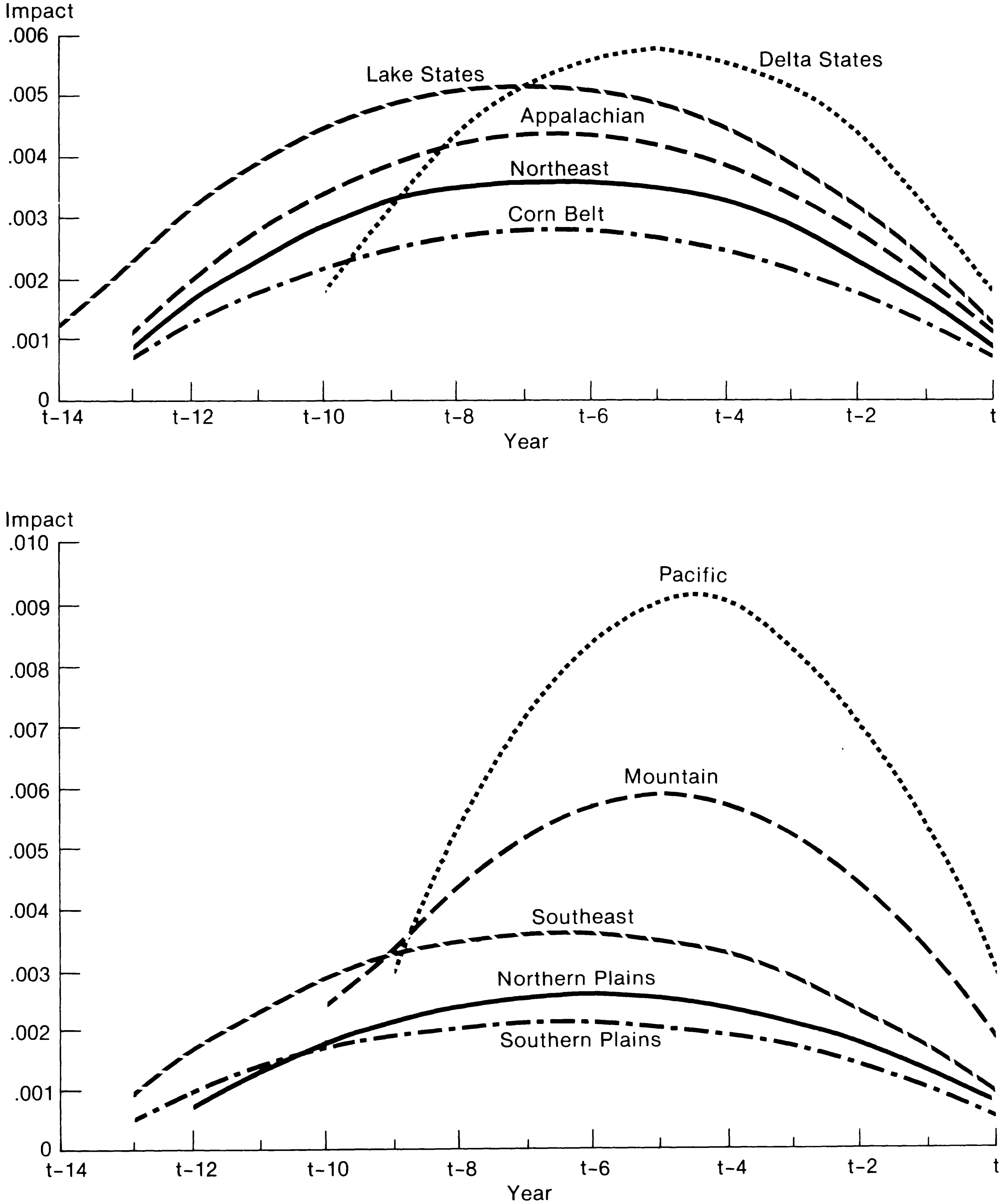


Table 2 — Estimates of distributed lag equations, by region

Variables	North east	Lake States	Corn Belt	Northern Plains	Appala-chian	South-east	Delta States	Southern Plains	Mountain	Pacific
Weather	0.0023 (3.7442)	0.0014 (2.2904)	0.0039 (7.6164)	0.0042 (13.7280)	0.0036 (5.0758)	0.0038 (5.4282)	0.0027 (6.4858)	0.0049 (8.7224)	0.0018 (4.9086)	0.0003 (0.7784)
Distributed lag weights in years:										
0	.0009	.0012	.0007	.0007	.0011	.0009	.0018	.0005	.0018	.0030
1	.0017	.0023	.0013	.0013	.0020	.0017	.0032	.0010	.0033	.0054
2	.0023	.0032	.0018	.0017	.0028	.0023	.0044	.0014	.0044	.0072
3	.0029	.0039	.0022	.0021	.0034	.0029	.0052	.0017	.0052	.0084
4	.0033	.0045	.0025	.0024	.0039	.0033	.0056	.0019	.0057	.0090
5	.0035	.0049	.0027	.0025	.0042	.0035	.0058	.0020	.0059	.0090
6	.0036	.0051	.0028	.0026	.0044	.0036	.0056	.0021	.0057	.0084
7	.0036	.0052	.0028	.0025	.0044	.0036	.0052	.0021	.0052	.0072
8	.0035	.0051	.0027	.0024	.0042	.0035	.0044	.0020	.0044	.0054
9	.0033	.0049	.0025	.0021	.0039	.0033	.0032	.0019	.0033	.0030
10	.0029	.0045	.0022	.0017	.0034	.0029	.0018	.0017	.0018	
11	.0023	.0039	.0018	.0013	.0028	.0023		.0014		
12	.0017	.0032	.0013	.0007	.0020	.0017		.0010		
13	.0009	.0023	.0007		.0011	.0009		.0005		
14		.0012								
Sum of weights	.0365	.0551	.0280	.0239	.0438	.0364	.0461	.0211	.0469	.0662
$\overline{R}^2$	.9111	.9833	.9859	.9904	.9912	.9774	.9237	.9940	.9937	.9975
Standard error of estimate	.0332	.0260	.0339	.0285	.0361	.0397	.0418	.0398	.0224	.0193
Durbin-Watson statistic	[1] 2.2900	[1] 2.0800	[1] 1.8900	[1] 2.0800	[1] 2.1600	[1] 2.0700	[1] 2.1500	[1] 1.7400	[1] 1.8400	[1] 1.4500
Autocorrelation coefficient	[2] .8290	[2] .7130	[2] .5760	[2] .5790	[2] .6860	[2] .6400	[2] .8280	[2] .2910	[2] .5770	[2] .4630

Numbers in parentheses are t-values.
[1] Third and fourth zeros after decimal point were added after rounding.
[2] Fourth zero after decimal point was added after rounding.

THE CONTRIBUTION OF R & E TO AGRICULTURAL PRODUCTION

Each dollar invested in agricultural research and extension (R & E) yields $4.30 over the 13-year lag period at the national level. If an interest rate of 5 percent is assumed, the present value of each dollar for its future return to agricultural R & E investment is $3.03. If a 6-percent interest rate is assumed, the present value decreases to $2.83.

At the national level, the internal rate of return to R & E investment for the national data is 26.5 percent. At the regional level, the internal rates of returns vary from 14.3 percent in the Southern Plains to 44.3 percent in the Pacific.

The sum of the estimated coefficients of the R & E variable, 0.037, suggests that a 1-percent increase in R & E expenditures will increase agricultural productivity 0.037 percent over a 13-year period. Although the impact of increased R & E on agricultural productivity is small, its implied impact on agricultural production is large. To determine this impact, we must first estimate the profitability of R & E investments.

Rates of Return to R & E

Given the specification of the model shown in equation (14), each single individual distributed lag coefficient is a direct estimate of the elasticity of agricultural productivity with respect to R & E expenditures in the appropriate time period:

$$\alpha_i = \frac{\partial \ln P_t}{\partial \ln R_{t-i}} = \frac{\partial P_t}{\partial R_{t-i}} \frac{R_{t-i}}{P_t}$$

or

$$\frac{\partial P_t}{\partial R_{t-i}} = \frac{\alpha_i P_t}{R_{t-i}}$$

As a first step in approximating the marginal product (MP) of R, the ratio of the average level of productivity to the average level of R & E expenditures over the selected time period was substituted for P_t/R_{t-i}:

$$\frac{\Delta P_t}{\Delta R_{t-i}} = \frac{\alpha_i \overline{P}}{\overline{R}} \tag{18}$$

where a bar over a variable name indicates the average of that variable. To ascertain the increase in agricultural output and/or input savings brought about by a $1 increase in R_{t-i}, we adjusted equation (18) by converting the numerator, P_t, to agricultural output (Y_t) net of input savings. The conversion is made by multiplying equation (18) by the average net increase in the value of output caused by a one index-point increase in productivity:

$$\frac{\Delta P_t}{\Delta R_{t-i}} \frac{\Delta Y_t}{\Delta P_t} = \frac{\alpha_i \overline{P}}{\overline{R}} \frac{\Delta Y}{\Delta P_t}$$

where the left-hand side expression can be reduced to

$$\frac{\Delta Y_t}{\Delta R_{t-i}},$$

which is the marginal product of R & E. Thus:

$$MP_{t-i} = \frac{\alpha_i \overline{P}}{\overline{R}} \frac{\Delta Y_t}{\Delta P_t}$$

Using the national data to calculate annual marginal products for a total lag of 13 years yields an estimated total marginal product of $4.30. This means that each $1 investment in R & E will yield $4.30 return over the 13-year period. As increments in output are distributed over time, future returns to R & E investment are discounted and the present value (PV) of a $1 investment in R & E is computed as follows:

Discount rate	Present value
Percent	*Dollars*
5	3.03
6	2.83
7	2.66
8	2.50
9	2.35
10	2.21
11	2.09
12	1.97
13	1.87

To compute the present value of the future returns, we must specify the discount rate. For a 5-percent discount rate, the present value is $3.03. If the discount rate increases to 6 percent, the present value reduces to $2.83.

Internal Rates of Return

Another criterion for evaluating an investment project's profitability is the internal rate of return, which is defined as that discount rate which equates discounted future returns with the initial investment. Based on the 1939-72 national data and the 13-year lag length, the internal rate of return to R & E is approximately 26.5 percent. However, this rate has changed over time; it has steadily declined from 30.5 percent in 1939-48 to 23.5 percent in 1969-72 as shown below:

Period	Rate of return
	Percent
1939-48	30.5
1949-58	27.5
1959-68	25.5
1969-72	23.5

In the foregoing analysis, only R & E investment in the public sector was emphasized; however, private R & E is assuming a greater role in agricultural production. In 1960 and 1965, for example, such expenditures accounted for about 45 percent of the total (*18*). Although most private R & E contributions are reflected in input prices, failure to account for the remainder could bias estimates of the profitability of public R & E programs. If private R & E is included in the theoretical model (14) and if private R & E has a positive contribution to agricultural productivity, both the estimated regression coefficients for the public R & E variables and the resulting marginal products and internal rates of return would be smaller. However, private R & E data are not available except for the U.S. estimate in 1960 and 1965. Without additional data, it is difficult to determine biases in profitability estimates of public R & E programs.

However, with this limited data, Evenson (*18*, pp. 71-72) used differences between "gross" and "net" productivity indexes to estimate indirectly the bias resulting from exclusion of private R & E. He estimated two productivity regressions—net productivity and gross productivity. The net productivity index differs from the gross productivity index in that inputs purchased from the industrial sector (that is, current operating expenses) are excluded from both input and output when computing the productivity index.

Therefore, the relative contribution of private R & E not reflected in the input prices can be obtained from the estimated gross and net coefficients and from the percentage of current operating expenses. For U.S. data, Evenson approximated that the estimated coefficients of public R & E variables are biased by a factor of 1.22.

Although Evenson's estimate of the bias resulting from exclusion of private R & E is rather crude, it is the best available. If our results are adjusted with the factor of 1.22, the marginal product for the 1939-72 U.S. data will be reduced from $4.30 to about $3.50.

Regional Differences in Rates of Return to R & E

The foregoing procedure was used to calculate the internal rates of return to production-oriented R & E programs for the 10 farm production regions (table 3).

Both adjusted and unadjusted rates of return vary widely, ranging from an adjusted rate of 14.3 percent in the Southern Plains to 44.3 percent in the Pacific. These differences in rates

Table 3 — Marginal internal rates of return to R & E investment, by region

Region	Lag length	Rate of return	Adjusted rate of return
	Year	*Percent*	
Northeast	13	20.0	16.4
Lake States	14	43.0	35.2
Corn Belt	13	33.5	27.4
Northern Plains	12	28.5	23.4
Appalachian	13	28.0	23.0
Southeast	13	18.5	15.2
Delta States	10	33.5	27.5
Southern Plains	13	17.5	14.3
Mountain	10	27.5	22.5
Pacific	9	54.0	44.3

of return may be explained by differences in R & E investment, the educational level of farmers, and weather. Using rank correlation, Cline (*11*) tested and accepted the hypotheses that the lower a region's production-oriented R & E expenditures per dollar of output, the higher the rate of return; the higher the educational level of farmers in a region, the higher the rate of return; and the better the absolute weather conditions in a region, the higher the rate of return. He also calculated the coefficient of concordance to test the strength of the relationship among these sets of rankings—rates of return, R & E expenditures, the educational level of farmers, and weather. Results indicated a rather weak relationship among these four rankings.

PROJECTIONS OF AGRICULTURAL PRODUCTIVITY

This section sets forth a productivity model for U.S. agriculture based on results of the regression analysis developed in the preceding section. We demonstrate that by determining research and extension (R & E) expenditures, decisionmakers can alter the growth rate of agricultural productivity.

We project three scenarios with differing R & E expenditures. Weather conditions similar to those in 1900-1972 are assumed, and farmers' educational levels are assumed to increase along an S-shaped curve.

Under a low technology scenario in which nominal increases in public expenditures for agricultural R & E are just offset by inflation, the annual growth rate is 1 percent. Under a baseline scenario in which real R & E grows 3 percent annually, the growth rate is 1.1 percent. The high technology scenario assumes that R & E grows 7 percent annually and that new and unprecedented agricultural technologies emerge as a consequence. The resulting growth rate is 1.3 percent. If the third scenario is projected to 2025 to allow more time for widespread adoption of the new technologies, productivity can be expected to maintain the 1.5-percent historical growth rate of the past 50 years.

Productivity Projection Model

From the results of the regression analysis in table 1, we can specify the following productivity simulator for U.S. agriculture:

$$\begin{aligned} P_t = {} & (R_t^{.0009})(R_{t-1}^{.0017})(R_{t-2}^{.0024}) \\ & (R_{t-3}^{.0029})(R_{t-4}^{.0033})(R_{t-5}^{.0036}) \\ & (R_{t-6}^{.0037})(R_{t-7}^{.0037})(R_{t-8}^{.0036}) \\ & (R_{t-9}^{.0033})(R_{t-10}^{.0029})(R_{t-11}^{.0024}) \\ & (R_{t-12}^{.0017})(R_{t-13}^{.0009})(E_t^{.7851})(e^{.0020\,W_t}) \end{aligned} \qquad (19)$$

To simulate future productivity growth using above model, we must project farmers' educational levels, weather conditions, and future R & E expenditures.

It may appear that the problem of projecting productivity has been shifted to projecting R & E expenditures, weather, and the educational level of farmers and farmworkers. This shift is necessary because productvity results from the interaction of these three sources, and R & E expenditures are important policy considerations. By controlling R & E expenditures, public decisionmakers can change the path of productivity growth.

The Education Index

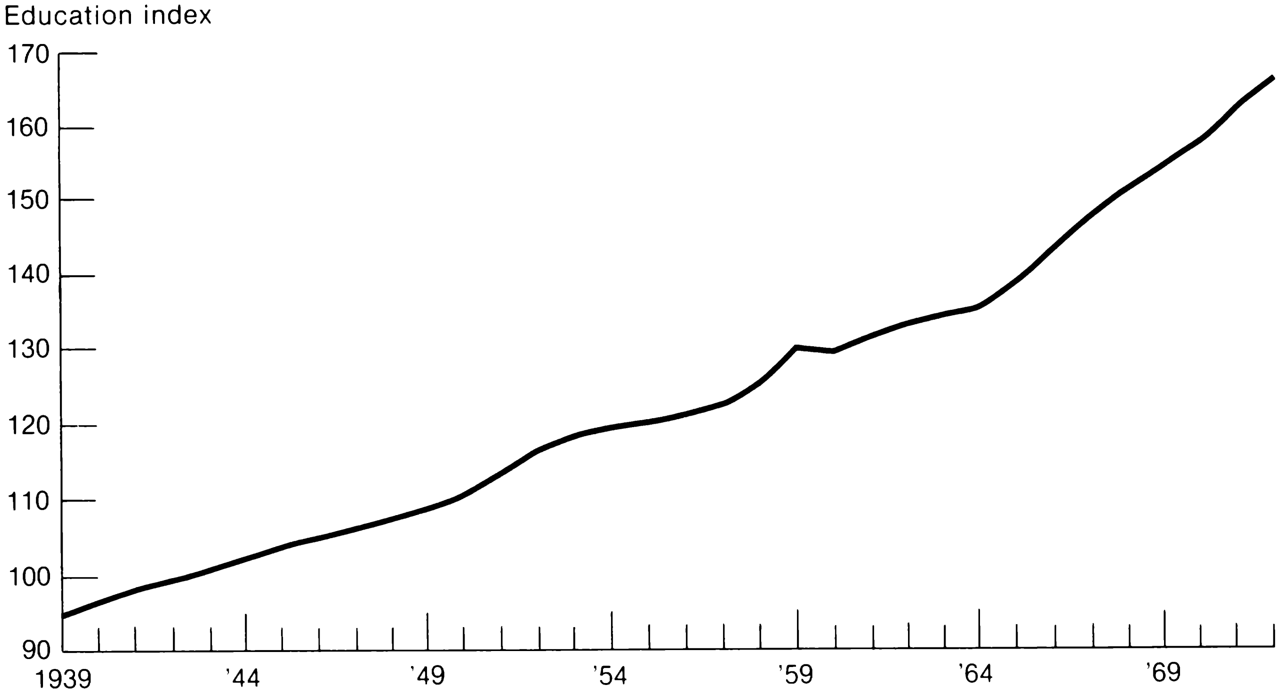
Figure 7 shows the 1939-72 educational index for farmers and farmworkers. Historically, the educational level of farmers and farmworkers has risen at a slightly increasing rate; however, it is unlikely that this trend will continue indefinitely. There is a practical limit to the education farmers can undertake. Therefore, it seems reasonable to assume that their educational attainment will eventually level off and approach a limit. It is hypothesized that education will follow an S-shaped curve of the following form:

$$E_t = k/(1 + be^{-at}) \qquad (20)$$

where E_t is the index of educational attain-

Figure 7

Index of Educational Attainment by Farmers and Farmworkers



ment by farmers and farm workers in the year t, k is the upper limit of the education index, and a and b are parameters. If k is known, equation (20) can be transformed into:

$$E_t^* = \ln b - at \qquad (21)$$

where: $E_t^* = \ln (k/E_t) - 1$

The parameters in equation (21) are estimated by ordinary least squares.

Assuming that the upper limit of the education index is 424 (that is, the level at which all farmers and farmworkers have at least 4 years of education beyond high school), we can fit the education index for 1939-72 to equation (21) with the following result:

$$E_t = 424/(1 + 3.682\, e^{-.029t})$$

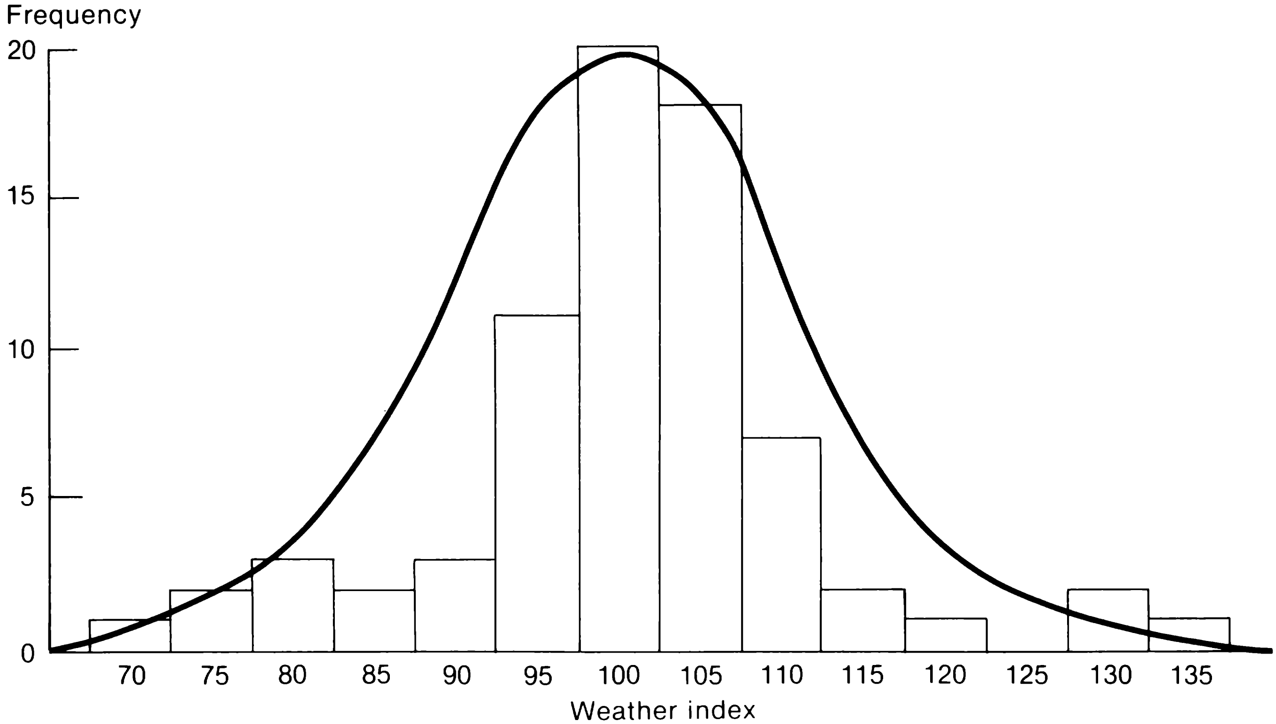
We then use this relationship to project the education index through the year 2000. It may be more plausible to expect an interaction between the educational level of farmers and R & E investments because changes in R & E support could shift the S-shaped growth curve. However, for simplicity, no such interaction was estimated.

The Weather Index

Although decisionmakers can exercise no significant control over weather, it is included in the model as a stochastic variable. By including this variable, a stochastic simulation technique can be used to project productivity change based on the probability distribution of the weather index. The frequency distribution of the weather index shown in figure 8 was obtained from the estimated weather index from 1900 to 1972. It appears that a normal distribution is a good approximation to the frequency distribution. The parameters of the normal distribution were obtained from the 1900-72

Figure 8

Distribution of Weather Indexes



weather index with the mean 100.7 and the standard deviation 11.4. These parameters were incorporated into the simulation routine to derive future values of the weather index.

R & E Expenditures

Whereas R & E expenditures increased during 1939-72 at an average annual rate of 3 percent, the growth rate from one short period to another changed substantially (fig. 9). The fastest growth—an average of about 10 percent annually—was observed in 1956-58, and the slowest growth was experienced in 1939-44 when R & E annual expenditures declined by 2.23 percent. In recent probability estimates, the Scenario Development Panel of USDA's Economics, Statistics, and Cooperatives Service (ESCS) estimated that the likelihood is greater than 80 percent that future R & E funding will be between 0 and 7 percent annually. Therefore, this research also assumes that future R & E expenditures will increase 0 to 7 percent annually.

Alternative Scenarios

After the quantitative relationship between agricultural productivity and its sources is established, future productivity growth can be projected by using the simulation model (19). Three scenarios are considered.

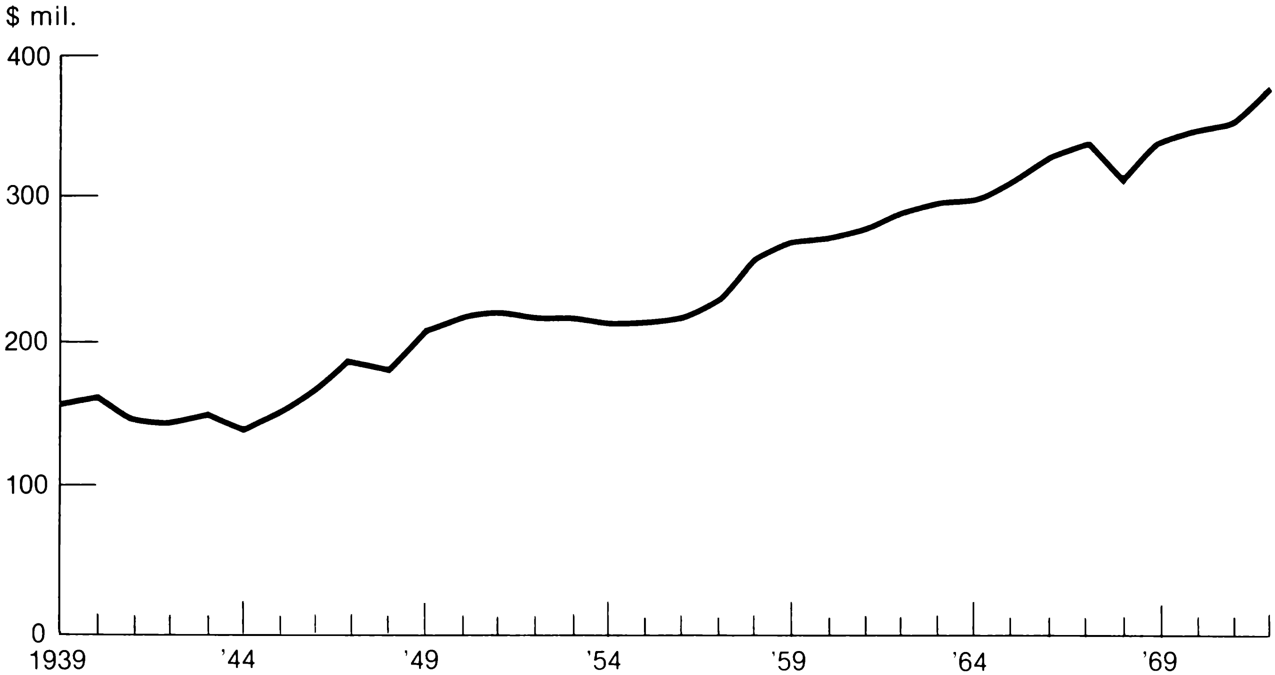
The first scenario is called the low technology scenario as it assumes a low level of investment in R & E to create new technology. Public R & E expenditures are maintained at a zero real growth rate.

Under the second scenario, it is assumed that the real R & E growth trend during 1939-72 will continue into the future; that is, real R & E expenditures will grow 3 percent per year. As this scenario uses the average R & E growth rate, we call it the baseline scenario.

The third scenario, high technology, assumes a 7-percent R & E growth rate to accelerate research and development of new technologies and to increase extension activities for dissemination of new technologies. Because of increased emphasis on R & E under this scenario, it is

Figure 9

Research and Extension Expenditures on Agricultural Production in the Public Sector



likely that more new technologies will become available for adoption. The impacts of possible unprecedented technologies on agricultural productivity are evaluated and incorporated into the productivity projections.

For all scenarios, the weather conditions (that is, the mean and the variability of the weather index) during 1900-72 are assumed to prevail and farmers' educational levels are assumed to increase along the S-shaped curve.

National and Regional Agricultural Productivity Projections

An extrapolated education index and future R & E expenditures under the three alternative scenarios were fed into the simulation model (19) to simulate future productivity change.

Figure 10 shows a simulated future path of productivity growth obtained by drawing only one weather observation from the weather distribution for each future year. This productivity growth path represents one of an infinite number of possible future paths. As the probability that future productivity growth will conform to this path is nearly zero, it is more meaningful to estimate the mean and distribution of the projected productivity index in a repeated sampling of the weather index. To provide us with usable or representative information, the computer generated 200 weather index values from the normal distribution to simulate future weather conditions for each year. The mean productivity index and its standard deviation as well as the maximum and minimum values have been computed.

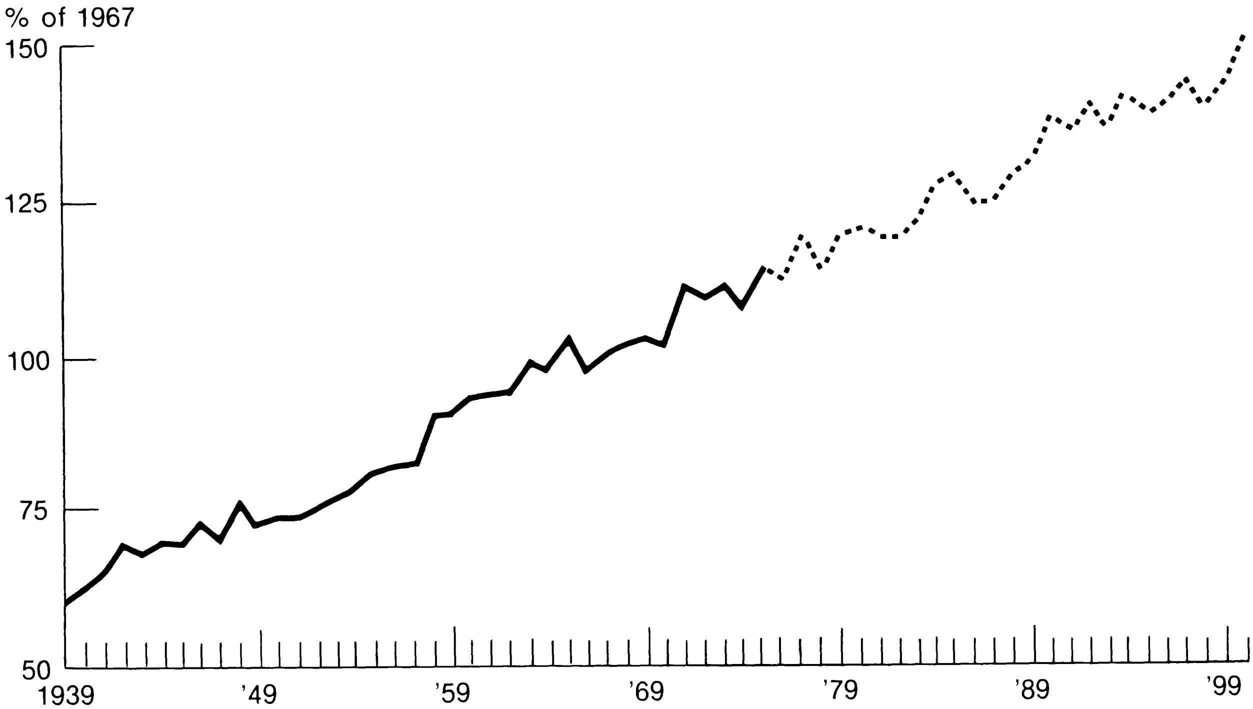
Aggregate U.S. Agricultural Productivity

The projected productivity index under scenarios 1 and 2 and for scenario 3 without the impacts of unprecedented technologies[10] for 1980-2000 are shown in tables 4, 5, and 6, respectively. For each table, the first column

[10]The impacts of emerging technologies will be incorporated into this projection after their impacts are evaluated (see following section).

Figure 10

A Sample Projection of U.S. Agricultural Productivity



shows the projected productivity index under normalized weather conditions. The standard deviation and the range (maximum and minimum) of the productivity index due to weather variability are shown in columns 2, 3, and 4. Column 5 shows the level of production-oriented R & E expenditures in 1958 dollars, and column 6 indicates the educational level of farmers (assumed to be the same for all scenarios).

As shown in table 4, under the low technology scenario, where public R & E expenditures are assumed to grow at a rate just offsetting the rate of inflation, the agricultural productivity index is expected to increase from a 1974-76 average of 112 to a range of 134 to 152 in the year 2000, depending on the weather, with an average of 144. The annual growth rate is about 1 percent.

The baseline scenario assumes that past R & E expenditure funding patterns will continue into the future. It is likely that the productivity index in the year 2000 will range from 137 to 155, with a mean of 146 under normalized weather conditions (table 5). The annual growth rate is about 1.1 percent.

Table 6 shows the projected productivity under the high technology scenario—without the impacts of unprecedented technologies. Note that agricultural output depends heavily on nature. During 1900-72, weather variations caused productivity to deviate from the trend more than 2.2 points in 1 of 3 years. Improved adaptation of crops to weather and weather modification have great potential for increasing productivity in agriculture. Accurate weather forecasts would contribute greatly. However, given the present state of knowledge, it is unlikely that such technological breakthroughs will occur by the year 2000.[11]

Regional Projections

Agricultural productivity indexes under these three scenarios were projected for the 10 farm

[11] This information is based on our interviews with specialists in the Science and Education Administration (SEA).

Table 4 — Projected agricultural productivity, United States: Scenario 1, 1980 to 2000

Year	Projected productivity indexes				Research and extension expenditures[1]	Education index
	Mean	Standard deviation	Maximum	Minimum		
	1967=100				*1,000 dollars*	
1980	118.11	2.87	125.01	110.35	371,953	176.08
1981	119.85	2.75	127.67	112.84	371,953	178.44
1982	120.66	2.76	127.30	113.18	371,953	180.81
1983	122.21	2.76	128.39	113.32	371,953	183.18
1984	123.71	2.92	133.03	115.85	371,953	185.57
1985	124.97	2.81	132.94	117.36	371,953	187.96
1986	125.73	2.77	131.67	118.37	371,953	190.36
1987	127.24	2.90	135.36	119.82	371,953	192.76
1988	128.66	3.12	136.15	119.85	371,953	195.17
1989	129.73	2.85	136.91	122.64	371,953	197.58
1990	131.16	3.23	143.14	123.56	371,953	200.00
1991	131.95	3.02	141.04	124.33	371,953	202.42
1992	133.26	3.10	140.78	125.84	371,953	204.84
1993	135.04	3.19	143.44	127.29	371,953	207.26
1994	135.95	3.03	143.27	128.99	371,953	209.69
1995	137.08	3.21	145.88	129.03	371,953	212.12
1996	138.40	3.25	147.73	130.26	371,953	214.54
1997	139.79	3.25	150.65	132.21	371,953	216.97
1998	140.98	3.18	150.21	132.26	371,953	219.39
1999	142.33	3.26	150.77	130.98	371,953	221.81
2000	143.56	3.34	151.93	134.35	371,953	224.23

[1] In 1958 dollars.

Table 5 — Projected agricultural productivity, United States: Scenario 2, 1980 to 2000

Year	Projected productivity indexes				Research and extension expenditures[1]	Education index
	Mean	Standard deviation	Maximum	Minimum		
	1967=100				*1,000 dollars*	
1980	118.19	2.83	124.82	111.49	444,132	176.08
1981	119.87	2.55	125.17	113.18	457,456	178.44
1982	121.12	2.73	129.71	113.95	471,179	180.81
1983	122.55	2.88	130.77	113.09	485,315	183.18
1984	123.98	2.77	133.32	114.95	499,874	185.57
1985	125.25	2.91	131.56	116.74	514,870	187.96
1986	126.93	2.86	133.46	118.93	530,317	190.36
1987	127.76	2.77	134.93	120.00	546,226	192.76
1988	129.60	3.08	136.87	120.83	562,613	195.17
1989	130.79	3.34	138.73	121.88	579,491	197.58
1990	132.14	3.28	141.25	124.84	596,876	200.00
1991	133.63	3.10	141.47	126.02	614,782	202.42
1992	134.93	3.02	142.56	126.64	633,226	204.84
1993	136.44	3.20	144.72	128.69	652,223	207.26
1994	137.70	3.29	148.28	128.91	671,789	209.69
1995	139.40	3.26	147.29	131.82	691,943	212.12
1996	140.39	3.29	148.98	131.72	712,701	214.54
1997	142.09	3.31	151.50	134.61	734,082	216.97
1998	143.83	3.68	153.58	132.92	756,105	219.39
1999	145.11	3.46	154.08	133.48	778,788	221.81
2000	145.94	3.42	154.89	136.80	802,151	224.23

[1] In 1958 dollars.

Table 6 — Projected agricultural productivity, United States: Scenario 3, 1980 to 2000

Year	Projected productivity indexes				Research and extension expenditures[1]	Education index
	Mean	Standard deviation	Maximum	Minimum		
	1967=100				*1,000 dollars*	
1980	118.93	2.86	127.67	110.77	558,202	176.08
1981	120.60	2.83	130.30	112.30	597,276	178.44
1982	121.84	2.71	130.73	113.87	639,085	180.81
1983	123.40	2.83	131.67	115.70	683,821	183.18
1984	125.06	2.86	133.17	117.96	731,689	185.57
1985	126.42	2.95	134.86	118.09	782,907	187.96
1986	128.33	2.97	136.56	121.65	837,710	190.36
1987	129.71	3.02	138.24	121.72	896,350	192.76
1988	131.58	3.10	140.32	123.40	959,095	195.17
1989	132.33	2.88	140.58	124.94	1,026,231	197.58
1990	135.05	3.19	143.86	128.51	1,098,067	200.00
1991	136.14	3.03	144.77	129.35	1,174,932	202.42
1992	137.73	3.37	146.99	128.76	1,257,177	204.84
1993	139.54	3.20	148.34	130.43	1,315,180	207.26
1994	141.17	3.49	150.44	133.49	1,439,342	209.69
1995	142.35	3.22	151.86	132.52	1,540,096	212.12
1996	144.77	3.40	153.64	136.58	1,647,903	214.54
1997	145.94	3.17	155.98	136.73	1,763,256	216.97
1998	147.91	3.66	156.79	138.06	1,886,684	219.39
1999	148.79	3.90	160.73	139.37	2,018,752	221.81
2000	150.67	3.34	159.34	142.51	2,160,065	224.23

[1] In 1958 dollars.

production regions through the year 2000 by using the same procedure as that for projecting the national productivity indexes. The parameters of the weather distributions for the 10 regions were computed from the 1939-72 weather index. Regional productivity simulation models were formulated by using the estimated coefficients in table 2. Appendix tables 1 through 30 present projected productivity indexes—including the mean, the standard deviation, and the range, as well as the education index, and R & E expenditures under the three scenarios—for each of the 10 farm production regions.

EMERGING AGRICULTURAL TECHNOLOGIES

Of the 12 technological breakthroughs identified by scientists as having the greatest potential impact on agricultural productivity by the year 2000, only 3 are considered to have an unprecedented potential. It is unlikely, however, that all of the three—photosynthesis enhancement and bioregulators in crop production and twinning in beef cattle production—would be ready for commercial adoption until the 1990's. Therefore, their projected impact on agricultural productivity by 2000 is small. However, if projections are extended to 2025 to allow time for widespread adoption, the productivity growth rate would be 1.5 percent annually—which equals the historical rate for the past 50 years.

Under a high technology scenario in which there is increased support for agricultural research and extension (R & E), it seems likely that these new and unprecedented technologies will not only be developed but will also be adopted by farmers. This would stimulate agricultural productivity, shifting its growth pattern to a new S-shaped curve.

Identification of Emerging Technologies

Past agricultural productivity growth has been examined, and future growth has been projected under the assumption that those forces which shaped past productivity growth will continue and that there will be no unprecedented technological breakthroughs.

Under the baseline scenario, agricultural productivity would continue to grow at about 1.1 percent per year, which is considerably less than the average annual growth rate of 1.5 percent over the past 50 years. Although the limit to growth would not be reached by the turn of the century under this scenario, the growth rate would decline. To prevent this situation from occurring, more investment in agricultural R & E is needed to accelerate the development of new technologies and to facilitate their adoption by farmers. With greater support for research, it is likely that more technologies will become available for adoption. It is assumed that new, unprecedented technologies will be developed and adopted by farmers under the high technology scenario, thereby shifting productivity growth to a new S-shaped curve.

Will there be technological breakthroughs in agriculture by the year 2000? What new agricultural technologies are being explored by scientists? Which technologies will have marked impacts on agricultural production? What is the probability of a particular technology's becoming available for commercial adoption by a specific year? What will be its adoption profile? What is the extent of the new technology's impact on crop and livestock production? To answer these questions, we at the USDA's Economic Research Service (now part of ESCS) conducted a study in 1974 in cooperation with Resources for the Future and the Ford Foundation (*9*). Existing literature on emerging technologies was reviewed, and researchers in the Agricultural Research Service, the Cooperative State Research Service, and the Extension Service—all now part of the Science and Education Administration (SEA)--were interviewed with modified Delphi and relevance-tree methods.

The literature review yielded an excellent study by Wittwer (*80*), who presented 10 future technologies which are on the scientific frontiers. These 10 technologies were included in the questionnaires and subsequent interviews with agricultural scientists confirmed most of them.

Scientists we interviewed identified the following 12 emerging technologies as having significant impact potential for agricultural productivity. Most of these technologies were also identified by the National Academy of Sciences study (*50*) as being on the scientific frontiers.

1. *Enhancement of photosynthetic efficiency.* Includes: (a) improvements in the process by which living plants form carbohydrates through genetic selection, physical modification, and chemical modification; (b) enhancement of the biological capacity of living plants to absorb nitrogen for protein synthesis; and (c) enhancement of the growth rates of agronomic plants through elevation of atmospheric levels of carbon dioxide.
2. *Water and fertilizer management.* Increased efficiency of input utilization through combined water and fertilizer management systems such as that developed for potatoes in Washington; also includes expanded trickle or drip irrigation, new subirrigation techniques, and foliar application of fertilizer.
3. *Crop pest control strategies.* Adoption of total pest management systems that incorporate resistant varieties, sex attractants, juvenile hormone analogs, and other biological controls which reduce energy inputs, environmental hazards, and pest control costs.
4. *Controlled environment or greenhouse agriculture.* Use of plastic or glass covers over plants with or without the addition of heat and carbon dioxide—a practice likely to continue to be restricted to high-value and speciality crops.
5. *Multiple and intensive cropping.* Double cropping and intensive cropping to increase annual yields per acre.
6. *Reduced tillage.* Expanded use of minimum or reduced tillage techniques, a process of minimizing the number of times farmers must cultivate a given field.
7. *Bioregulators.* Natural and synthetic compounds which regulate the ripening and senescence of horticultural products. They can be applied at the preharvest stage to enhance ripening and to facilitate mechanical harvesting. When applied after harvest, they can slow down life processes and prolong shelf life of some fruits and vegetables and reduce cooling costs.
8. *New Crops.* Development of new and improved hybrids and search for alternate food crops.
9. *Bioprocessing.* An extension of traditional agricultural production so that unpalatable raw products, such as cellulose and petroleum materials, can be converted into edible protein, carbohydrates, and fats—a process which will provide additional feed sources for animals.
10. *Antitranspirants.* Inhibition of plants' tendency to lose water through evaporation.
11. *Development of plants to withstand drought and salinity.* Genetic development of plants which are more drought resistant and which thrive on saline water.
12. *Twinning.* Multiple births in beef cattle through (a) breeding and selection of livestock for twinning genetic traits, (b) multiple ovulation through hormonal control, and (c) embryo transfer.

Most researchers believe that many of these emerging technologies will be required to maintain present productivity growth patterns in the face of new constraints. As a result, their impacts have already been captured in the base projections. Only three technologies—twinning in beef cattle, bioregulators, and photosynthesis enhancement—are considered to have potentially unprecedented impacts on agricultural productivity, and they are included in the high technology scenario. The development of these three technologies was partly confirmed by a recent study by the Office of Technology Assessment (*52*). In that study, a panel of scientists representing agricultural and non-agricultural interests, private research organizations, and industries identified three areas of basic research which possess great opportunity for fundamental scientific discoveries. These areas are photosynthesis, nitrogen fixation, and genetic engineering for plants; the first two areas were also identified in the present study as possibly having unprecedented impacts on agricultural productivity. As photosynthesis and nitrogen fixation are closely related, they have been combined into a single technology—photosynthesis enhancement.

Impact Analysis

To estimate the impacts of these three emerging technologies on agricultural productivity, we obtained the following information for each technology:

1. The subjective probability distribution; the probability of the occurrence of each new technology in year t (q_t), where t = 1, 2, 3, ... , n, and the year 1 denotes the first year of projections.
2. The adoption profile; the percentage of crop or livestock output affected by the new technology in the *i*th year of adoption (a_i), where i = 1, 2, ... , n.
3. The specific crops or livestock affected by the impacts.
4. Increases in productivity of the affected crops or livestock, measured by the ratio of increased output to increased inputs in constant dollar values, given adoption of the new technology (f).
5. Output of affected crops or livestock as a percentage of the total output (r).

Adoption profiles vary among different technologies. The length of time from introduction to the point that adoption reaches its maximum ranges from about 35 years for twinning in beef cattle production to over 50 years for photosynthesis enhancement. For each technology, this adoption rate is expected to be slow at the initial stage. As more farmers are attracted to the new technology, this rate is expected to increase exponentially. Then the rate of increase will decline, and the percentage of adoption will gradually approach a ceiling as a saturation point is reached.

As shown in figure 11, after the first year of commercial introduction, the percentage of adoption is a_1; after the second year, a_2; the third year, a_3; and so forth. It is also assumed that the adoption profile will remain the same regardless of when the technology becomes commercially available. The adoption curve A_1 refers to the adoption profile when the technology is introduced in year 1; A_2, the adoption profile for year 2; and A_3, for year 3; and so forth.

Let us assume that the *j*th technology is introduced for commercial adoption in the year t. If fully adopted, it will increase productivity of the affected commodities f_j percent. In the year k, that is, k−t after commercial introduction, adoption of the *j*th technology will increase productivity of the affected commodities $a_{k-t}f_j$ percent. Let us assume further that the affected commodities constitute r_j percent of the total output; thus, the impact of the *j*th technology on productivity of the total farm sector in the year k is:

$$I_{kj} = a_{k-t}\, r_j\, f_j$$

where t denotes the year of commercial introduction.

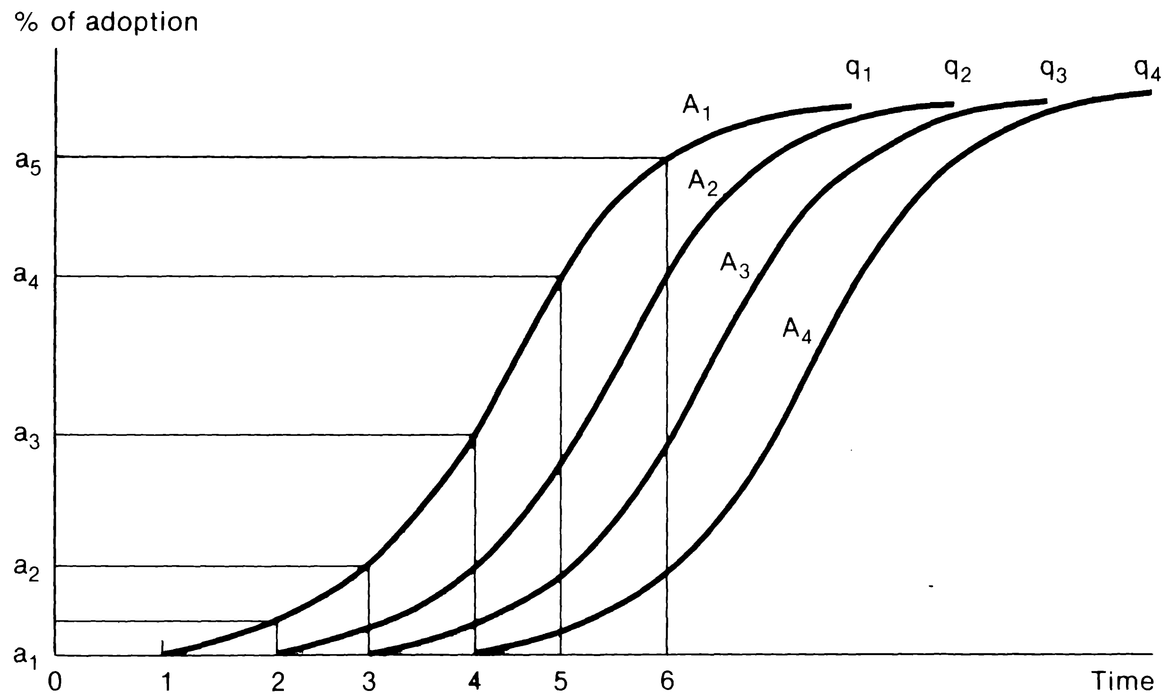
The above equation denotes the impact on agricultural productivity when the *j*th technology is actually introduced in year t. However, we do not know with certainty that any particular technology will be introduced in a specific year. Only the subjective probability distribution of occurrence for each new technology in year t can be determined. To illustrate, let us consider the simplified case in figure 12. In year 5 (k=5), technology introduced in years 1 through 4 only will have an impact. If the technology is introduced in year 1 (t=1), the impact in year 5 will be the impact in the fourth year of adoption (k−t = 5−1 = 4) I_4. If the technology is introduced in year 2, the impact in year 5 will be I_3. Likewise, the impacts of the technology introduced in years 3 and 4 will be I_2 and I_1, respectively. As the probability that the technology will be introduced in year 1 is q_1, in year 2 is q_2, in year 3 is q_3, and year 4 is q_4, the expected value of the impacts of the technology in year 5 is:

$$X_5 = q_1 I_4 + q_2 I_3 + q_3 I_2 + q_4 I_1$$

Generally the expected value of the impacts of the *j*th technology in the kth year is:

Figure 11

Profile of Technology Adoption by Farmers



$$X_{kj} = \sum_{t=1}^{k-1} q_{tj} \, I_{kj}$$

Let us further assume that the impacts of the three technologies are additive. The total expected increase in productivity due to the adoption of the three technologies in year k can be obtained by:

$$X_{k.} = \sum_{j=1}^{3} X_{kj} = \sum_{j=1}^{3} \sum_{t=1}^{k-1} q_{tj} \, I_{kj}$$

The estimated impacts of these three technologies on productivity projections have also been incorporated under the high technology scenario.

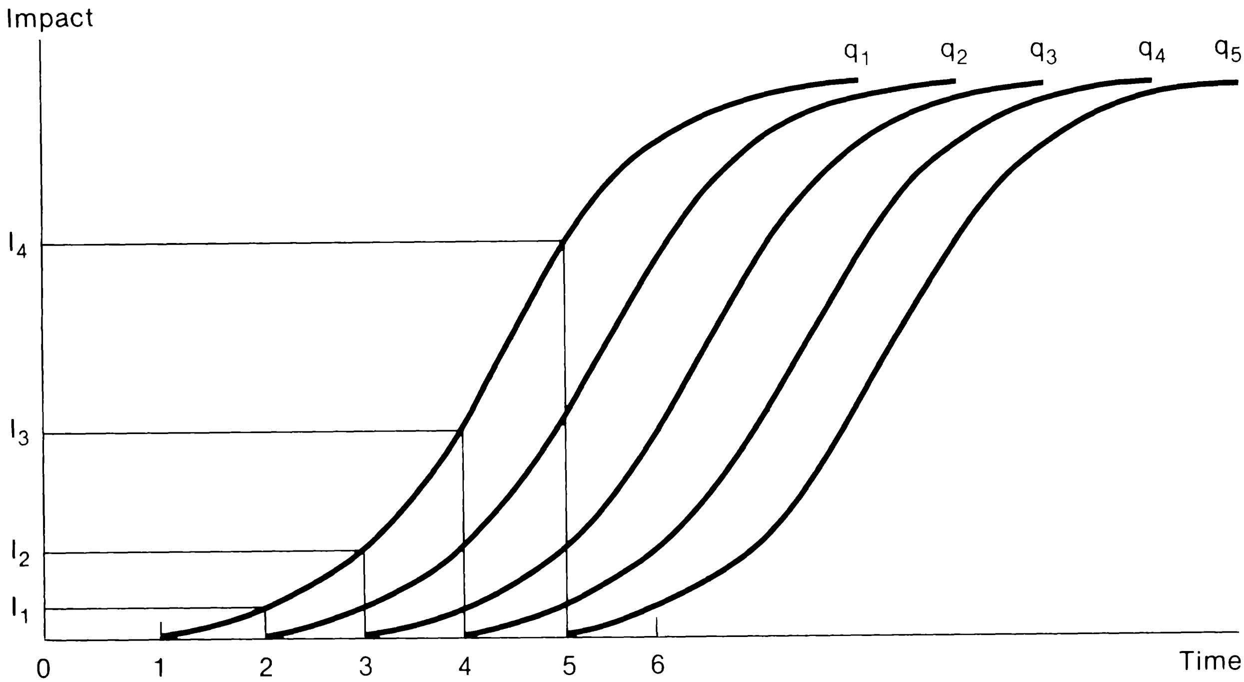
These impacts on agricultural productivity for the United States and the 10 farm production regions are shown in tables 7 through 17. Expected increases in productivity resulting from adoption of twinning, bioregulators, photosynthesis enhancement, and the combination of all three technologies are listed in columns 1 through 4. Column 5 shows the expected values of projected productivity which account for the three technologies' possible impacts, and column 6 shows productivity projections assuming all three technologies become available for adoption in the earliest year mentioned either in the literature or by the agricultural researchers we interviewed. Column 6 shows the most optimistic projections.

Impacts on productivity were also translated into dollar values of additional output. The expected dollar value of additional output resulting from the impacts of all three technologies is presented in column 7, and the dollar value of additional output assuming the three technologies become available at the earliest date is shown in column 8. All values are expressed in thousands of 1958 dollars.

For the year 2000, expected increases in the productivity index resulting from twinning, bioregulators, and photosynthesis enhancement are 1.4, 3.7, and 0.4, respectively. If these three

Figure 12

Impact of New Technology on Agricultural Productivity



emerging technologies become available for adoption commercially as anticipated, their impacts would cause the productivity growth curve to shift to a new S-shaped curve.

As most of these technologies would not be ready for adoption commercially until the 1990's and as it takes decades to complete the adoption processes, their projected impacts on agricultural productivity by the year 2000 will be small. As shown in column 5, productivity would grow from the 1974-76 average of 112 to 156 in the year 2000 at an average annual rate of 1.3 percent. This growth rate is less than the historical rate of 1.5 percent for the past 50 years. However, if this trend is projected to 2025 to allow more time for widespread adoption, productivity would be expected to grow an average of 1.5 percent per year. Under the most optimistic projection shown in column 6, this same growth rate can also be achieved before the year 2000.

Table 7 — United States: Impacts of emerging technologies on agricultural productivity, 1980-2000

Year	Expected increase in productivity indexes due to				Productivity index		Value of additional output[1]	
	Twinning	Bioregulators	Photo-synthesis enhancement	Total	Expected	Maximum	Expected	Maximum
	1967=100						*1,000 dollars*	
1980	0	0	0	0	118.93	119.88	1,022	352,263
1981	0	.01	0	.01	120.60	121.54	2,136	427,838
1982	0	.01	0	.01	121.85	123.34	4,244	541,333
1983	0	.02	0	.02	123.42	125.17	8,037	657,548
1984	0	.04	0	.04	125.10	127.02	14,503	776,538
1985	0	.07	0	.07	126.49	129.19	24,959	991,225
1986	0	.12	0	.12	128.45	131.12	40,983	1,117,158
1987	0	.19	0	.19	129.90	133.36	64,310	1,341,267
1988	0	.28	0	.28	131.86	135.34	96,572	1,474,259
1989	0	.40	0	.41	132.74	137.51	139,151	1,668,343
1990	0	.56	0	.56	135.61	139.63	193,061	1,844,813
1991	0	.75	.01	.76	136.90	142.07	259,125	2,125,008
1992	0	.97	.02	.99	138.72	144.22	338,325	2,310,167
1993	.01	1.22	.03	1.26	140.80	147.16	432,574	2,760,466
1994	.04	1.50	.05	1.59	142.76	150.00	544,859	3,178,736
1995	.09	1.82	.08	1.98	144.33	152.89	679,720	3,506,402
1996	.19	2.15	.12	2.46	147.23	155.79	842,589	4,042,787
1997	.35	2.51	.17	3.03	148.97	158.73	1,039,543	4,488,424
1998	.59	2.89	.24	3.72	151.65	151.58	1,275,688	4,899,741
1999	.93	3.27	.33	4.53	153.32	154.44	1,553,732	5,318,777
2000	1.37	3.66	.43	5.46	156.13	167.34	1,873,612	5,746,221

[1] In 1958 dollars.

Table 8 — Northeast: Impacts of emerging technologies on agricultural productivity, 1980-2000

Year	Expected increase in productivity indexes due to				Productivity index		Value of additional output[1]	
	Twinning	Bioregulators	Photo-synthesis enhancement	Total	Expected	Maximum	Expected	Maximum
	1967=100						*1,000 dollars*	
1980	0	0	0	0	115.02	115.52	66	23,533
1981	0	0	0	0	116.14	117.06	143	28,580
1982	0	.01	0	.01	117.94	118.92	284	36,220
1983	0	.02	0	.02	119.43	120.44	537	43,936
1984	0	.03	0	.03	120.61	122.22	970	51,913
1985	0	.05	0	.05	122.54	124.10	1,669	62,445
1986	0	.09	0	.09	124.04	125.85	2,739	70,804
1987	0	.14	0	.14	125.34	127.71	4,296	81,774
1988	0	.21	0	.21	127.08	129.51	6,446	90,557
1989	0	.30	0	.30	128.64	131.31	9,276	99,367
1990	0	.41	0	.41	130.23	133.11	12,846	107,838
1991	0	.55	0	.55	131.94	135.01	17,188	119,016
1992	0	.71	0	.71	133.47	136.82	22,325	127,860
1993	0	.89	.01	.90	135.48	138.87	28,297	143,556
1994	.01	1.10	.01	1.12	137.45	140.85	35,164	156,794
1995	.03	1.33	.02	1.37	139.02	142.83	43,010	170,296
1996	.05	1.57	.03	1.66	140.78	144.82	51,938	184,062
1997	.10	1.84	.05	1.98	142.66	146.83	62,041	198,107
1998	.17	2.11	.07	2.34	144.74	148.75	73,362	209,505
1999	.26	2.39	.09	2.74	146.93	150.68	85,875	221,105
2000	.38	2.67	.12	3.18	148.63	152.63	99,475	232,923

[1] In 1958 dollars.

Table 9 — Lake States: Impacts of emerging technologies on agricultural productivity, 1980-2000

Year	Expected increase in productivity indexes due to				Productivity index		Value of additional output[1]	
	Twinning	Bioregulators	Photo-synthesis enhancement	Total	Expected	Maximum	Expected	Maximum
	1967=100						*1,000 dollars*	
1980	0	0	0	0	114.20	115.12	80	27,735
1981	0	.01	0	.01	115.63	116.78	167	33,713
1982	0	.01	0	.01	117.22	118.57	335	42,691
1983	0	.02	0	.02	118.73	120.40	634	51,906
1984	0	.04	0	.04	120.38	122.27	1,146	61,362
1985	0	.06	0	.06	122.05	124.34	1,974	76,479
1986	0	.10	0	.10	123.49	126.29	3,244	86,509
1987	0	.16	0	.16	125.40	128.43	5,095	102,359
1988	0	.23	0	.24	127.08	130.45	7,658	112,985
1989	0	.34	0	.34	128.95	132.57	11,044	126,470
1990	0	.47	0	.47	130.77	134.68	15,330	139,210
1991	0	.63	0	.63	132.73	136.99	20,575	158,123
1992	0	.81	.01	.82	134.71	139.15	26,845	171,548
1993	.01	1.02	.02	1.05	136.54	141.80	34,251	201,124
1994	.03	1.26	.03	1.32	138.58	144.38	42,976	228,070
1995	.06	1.53	.05	1.64	140.74	147.00	53,290	255,673
1996	.12	1.82	.07	2.01	142.87	149.63	65,513	283,903
1997	.23	2.12	.11	2.46	145.03	152.30	80,013	312,783
1998	.39	2.44	.15	2.98	147.48	154.89	97,061	338,811
1999	.61	2.77	.21	3.58	149.88	157.49	116,800	365,387
2000	.90	3.10	.27	4.27	152.22	160.13	139,183	392,536

[1] In 1958 dollars.

Table 10 — Corn Belt: Impacts of emerging technologies on agricultural productivity, 1980-2000

Year	Expected increase in productivity indexes due to				Productivity index		Value of additional output[1]	
	Twinning	Bioregulators	Photo-synthesis enhancement	Total	Expected	Maximum	Expected	Maximum
	1967=100						*1,000 dollars*	
1980	0	0	0	0	109.56	111.52	356	122,892
1981	0	.01	0	.01	111.60	113.09	745	149,196
1982	0	.02	0	.02	112.13	114.81	1,479	188,686
1983	0	.03	0	.03	113.94	116.56	2,800	229,072
1984	0	.05	0	.05	115.70	118.35	5,050	270,412
1985	0	.09	0	.09	117.11	120.46	8,686	342,327
1986	0	.15	0	.15	117.72	122.30	14,254	385,914
1987	0	.24	0	.24	119.63	124.48	22,351	460,835
1988	0	.35	0	.35	121.44	126.36	33,541	506,706
1989	0	.51	0	.51	122.70	128.44	48,292	570,952
1990	0	.70	0	.71	124.63	130.40	66,944	623,022
1991	0	.94	.01	.95	125.51	132.71	89,738	707,932
1992	0	1.21	.02	1.24	127.33	134.70	116,945	762,493
1993	.01	1.53	.03	1.57	129.99	137.45	149,003	887,616
1994	.03	1.88	.05	1.97	131.26	140.06	186,631	1,000,886
1995	.08	2.27	.09	2.44	132.97	142.70	230,844	1,116,424
1996	.16	2.70	.13	2.99	135.10	145.37	282,875	1,234,231
1997	.29	3.14	.20	3.63	137.44	148.07	344,018	1,354,408
1998	.50	3.61	.28	4.39	139.57	150.63	415,241	1,461,795
1999	.76	4.09	.38	5.25	142.07	153.22	496,965	1,571,149
2000	1.15	4.57	.50	6.22	144.51	155.82	588,859	1,682,467

[1] In 1958 dollars.

Table 11 — Northern Plains: Impacts of emerging technologies on agricultural productivity, 1980-2000

Year	Expected increase in productivity indexes due to				Productivity index		Value of additional output[1]	
	Twinning	Bioregulators	Photo-synthesis enhancement	Total	Expected	Maximum	Expected	Maximum
	1967=100						*1,000 dollars*	
1980	0	0	0	0	111.52	113.90	90	30,908
1981	0	.01	0	.01	113.84	115.40	187	37,519
1982	0	.01	0	.01	114.81	117.01	372	47,445
1983	0	.02	0	.02	116.41	118.65	704	57,598
1984	0	.04	0	.04	117.94	120.31	1,270	67,979
1985	0	.06	0	.06	119.03	122.25	2,184	87,790
1986	0	.10	0	.10	121.37	123.95	3,583	98,748
1987	0	.16	0	.16	121.03	125.93	5,617	119,341
1988	0	.24	0	.24	123.95	127.66	8,430	130,872
1989	0	.34	0	.35	124.82	129.58	12,139	148,840
1990	0	.48	0	.48	126.18	131.60	16,834	170,704
1991	0	.64	.01	.64	127.97	133.93	22,604	202,868
1992	.01	.82	.01	.84	129.27	135.99	29,593	225,751
1993	.02	1.04	.03	1.09	131.26	139.14	38,095	286,563
1994	.07	1.27	.05	1.39	132.53	142.22	48,620	345,037
1995	.15	1.54	.07	1.76	135.25	145.33	61,915	404,669
1996	.32	1.82	.11	2.25	135.84	148.49	78,964	465,514
1997	.58	2.13	.16	2.87	138.80	151.67	100,857	527,548
1998	.99	2.44	.23	3.66	142.15	154.79	128,580	586,993
1999	1.56	2.76	.31	4.64	144.12	157.93	162,780	647,549
2000	2.30	3.09	.41	5.80	144.87	161.11	203,588	709,214

[1] In 1958 dollars.

Table 12 — Appalachian: Impacts of emerging technologies on agricultural productivity, 1980-2000

Year	Expected increase in productivity indexes due to				Productivity index		Value of additional output[1]	
	Twinning	Bioregulators	Photo-synthesis enhancement	Total	Expected	Maximum	Expected	Maximum
	1967=100						1,000 dollars	
1980	0	0	0	0	125.86	126.25	43	14,694
1981	0	0	0	0	127.81	127.94	89	17,853
1982	0	.01	0	.01	129.03	129.71	177	22,597
1983	0	.01	0	.01	130.77	131.52	336	27,459
1984	0	.02	0	.02	132.69	133.36	606	32,441
1985	0	.04	0	.04	134.07	135.63	1,044	48,388
1986	0	.06	0	.06	136.40	137.53	1,716	53,760
1987	0	.10	0	.10	137.82	139.89	2,696	70,386
1988	0	.15	0	.15	140.10	141.85	4,058	76,159
1989	0	.21	0	.22	140.48	144.20	5,869	91,827
1990	0	.30	.01	.30	144.24	146.27	8,164	100,077
1991	0	.40	.01	.41	145.23	148.80	11,065	120,206
1992	0	.51	.02	.54	147.10	150.91	14,591	128,970
1993	.01	.65	.04	.70	149.38	153.76	18,896	157,707
1994	.02	.80	.07	.89	151.37	156.58	24,183	185,363
1995	.06	.96	.11	1.13	152.65	159.44	30,733	213,651
1996	.12	1.14	.17	1.43	156.09	162.31	38,878	242,562
1997	.22	1.34	.25	1.81	157.48	165.22	48,980	272,112
1998	.37	1.54	.36	2.26	160.33	168.09	61,345	300,453
1999	.56	1.74	.49	2.81	161.41	170.99	76,174	329,398
2000	.86	1.95	.65	3.45	164.27	173.92	93,504	358,952

[1] In 1958 dollars.

Table 13 — Southeast: Impact of emerging technologies on agricultural productivity, 1980-2000

Year	Expected increase in productivity indexes due to				Productivity index		Value of additional output[1]	
	Twinning	Bioregulators	Photo-synthesis enhancement	Total	Expected	Maximum	Expected	Maximum
	1967=100						*1,000 dollars*	
1980	0	0	0	0	124.43	125.61	85	29,316
1981	0	.01	0	.01	125.63	127.37	178	35,603
1982	0	.01	0	.01	127.10	129.27	353	45,048
1983	0	.03	0	.03	128.91	131.20	669	54,714
1984	0	.05	0	.05	130.24	133.17	1,207	64,615
1985	0	.08	0	.08	132.59	135.37	2,077	79,493
1986	0	.13	0	.13	132.97	137.41	3,409	89,933
1987	0	.21	0	.21	135.41	139.68	5,348	105,472
1988	0	.32	0	.32	137.00	141.78	8,027	116,467
1989	0	.46	0	.46	138.63	143.96	11,559	129,400
1990	0	.63	0	.63	141.10	146.07	16,018	140,234
1991	0	.84	.01	.85	141.89	148.39	21,455	156,383
1992	0	1.09	.01	1.10	144.32	150.53	27,910	167,731
1993	.01	1.37	.02	1.40	146.57	153.10	35,442	190,003
1994	.02	1.69	.03	1.74	148.20	155.56	44,153	209,290
1995	.04	2.05	.05	2.14	150.27	158.04	54,174	228,972
1996	.09	2.43	.08	2.60	152.63	160.54	65,666	249,064
1997	.16	2.83	.12	3.11	155.01	163.06	78,770	269,552
1998	.28	3.25	.17	3.70	157.90	165.45	93,574	286,806
1999	.44	3.69	.23	4.35	159.63	167.87	110,074	304,395
2000	.64	4.12	.30	5.06	162.40	170.30	128,139	322,303

[1] In 1958 dollars.

Table 14 — Delta States: Impacts of emerging technologies on agricultural productivity, 1980-2000

Year	Expected increase in productivity indexes due to				Productivity index		Value of additional output[1]	
	Twinning	Bioregulators	Photo-synthesis enhancement	Total	Expected	Maximum	Expected	Maximum
	1967=100						1,000 dollars	
1980	0	0	0	0	121.58	123.11	76	26,340
1981	0	.01	0	.01	123.80	124.91	160	32,012
1982	0	.01	0	.01	126.14	126.90	316	40,537
1983	0	.03	0	.03	127.22	128.92	602	49,282
1984	0	.05	0	.05	129.98	131.00	1,088	58,258
1985	0	.08	0	.08	130.23	133.61	1.875	79,036
1986	0	.14	0	.14	131.67	135.75	3,081	88,624
1987	0	.21	0	.21	133.71	138.42	4,640	110,316
1988	0	.32	0	.32	135.65	140.60	7,228	120,513
1989	0	.46	0	.46	138.25	143.20	10,506	140,171
1990	0	.63	.01	.64	139.35	145.44	14,609	151,635
1991	0	.85	.01	.86	141.26	148.27	19,662	175,866
1992	0	1.10	.03	1.13	143.64	150.56	25,748	187,998
1993	.01	1.39	.05	1.45	145.00	153.77	32,996	220,863
1994	.03	1.71	.09	1.83	147.70	156.88	41,599	251,328
1995	.07	2.06	.14	2.27	148.97	160.04	51,822	282,505
1996	.14	2.45	.22	2.81	152.24	163.21	63,962	314,342
1997	.25	2.86	.32	3.44	153.90	166.44	78,339	346,902
1998	.43	3.29	.46	4.18	157.25	169.55	95,188	376,843
1999	.68	3.73	.62	5.03	160.40	172.71	114,630	407,416
2000	1.00	4.17	.82	5.99	162.58	175.88	136,613	438,601

[1] In 1958 dollars.

Table 15 — Southern Plains: Impacts of emerging technologies on agricultural productivity, 1980-2000

Year	Expected increase in productivity indexes due to				Productivity index		Value of additional output[1]	
	Twinning	Bioregulators	Photo-synthesis enhancement	Total	Expected	Maximum	Expected	Maximum
	1967=100						*1,000 dollars*	
1980	0	0	0	0	117.87	119.31	33	11,314
1981	0	0	0	0	119.74	120.77	69	13,732
1982	0	.01	0	.01	120.70	122.29	136	17,361
1983	0	.01	0	.01	122.71	123.84	256	21,071
1984	0	.02	0	.02	123.76	125.39	464	24,863
1985	0	.03	0	.03	124.52	127.23	799	34,398
1986	0	.05	0	.05	126.99	128.83	1,311	39,433
1987	0	.08	0	.08	128.92	130.71	2,056	50,364
1988	0	.13	0	.13	130.12	132.34	3,088	54,646
1989	0	.18	0	.18	130.59	134.20	4,455	64,726
1990	0	.25	0	.25	132.49	136.18	6,196	77,510
1991	0	.33	.01	.34	134.66	138.45	8,366	97,678
1992	.01	.43	.02	.46	134.45	140.47	11,073	111,073
1993	.02	.55	.03	.60	137.78	143.60	14,534	151,712
1994	.07	.67	.05	.79	138.63	146.70	19,128	191,854
1995	.16	.81	.08	1.04	141.60	149.84	25,416	232,818
1996	.33	.96	.12	1.40	141.74	153.02	34,130	274,593
1997	.61	1.12	.17	1.89	144.42	156.24	46,102	317,201
1998	1.03	1.28	.24	2.55	146.69	159.42	62,097	359,223
1999	1.62	1.45	.33	3.40	148.71	162.64	82,652	402,028
2000	2.38	1.62	.43	4.44	151.29	165.89	107,938	445,615

[1] In 1958 dollars.

Table 16 — Mountain: Impacts of emerging technologies on agricultural productivity, 1980-2000

Year	Expected increase in productivity indexes due to				Productivity index		Value of additional output[1]	
	Twinning	Bioregulators	Photo-synthesis enhancement	Total	Expected	Maximum	Expected	Maximum
	1967=100						1,000 dollars	
1980	0	0	0	0	120.21	120.87	42	14,322
1981	0	0	0	0	121.46	122.58	87	17,409
1982	0	.01	0	.01	123.07	124.42	173	22,050
1983	0	.02	0	.02	124.84	126.28	326	26,809
1984	0	.03	0	.03	126.23	128.18	592	31,693
1985	0	.05	0	.05	127.88	130.29	1,020	40,198
1986	0	.08	0	.08	129.86	132.24	1,676	45,376
1987	0	.13	0	.13	131.59	134.39	2,631	54,269
1988	0	.19	0	.20	133.30	136.37	3,953	59,744
1989	0	.28	0	.28	135.30	138.47	5,699	67,416
1990	0	.39	0	.39	136.77	140.85	7,913	80,592
1991	0	.52	.01	.53	139.07	143.44	10,641	97,860
1992	.01	.67	.01	.69	140.79	145.86	13,975	111,715
1993	.03	.85	.02	.89	142.80	149.44	18,107	148,563
1994	.08	1.05	.03	1.15	144.58	152.98	23,375	184,575
1995	.18	1.26	.05	1.49	146.73	156.56	30,290	221,423
1996	.38	1.50	.08	1.95	149.13	160.20	39,533	259,142
1997	.70	1.75	.11	2.56	151.35	163.88	51,869	297,706
1998	1.19	2.01	.16	3.36	154.22	167.52	68,013	335,317
1999	1.87	2.28	.21	4.37	156.98	171.21	88,466	373,756
2000	2.76	2.56	.28	5.60	159.88	174.95	113,375	413,028

[1] in 1958 dollars.

Table 17 — Pacific: Impacts of emerging technologies on agricultural productivity, 1980-2000

Year	Expected increase in productivity indexes due to				Productivity index		Value of additional output[1]	
	Twinning	Bioregulators	Photo-synthesis enhancement	Total	Expected	Maximum	Expected	Maximum
	1967=100						*1,000 dollars*	
1980	0	0	0	0	141.35	142.38	88	30,222
1981	0	.01	0	.01	143.36	144.63	184	36,788
1982	0	.01	0	.01	145.51	147.05	366	46,652
1983	0	.02	0	.02	147.63	149.53	694	56,806
1984	0	.04	0	.04	149.81	152.07	1,256	67,252
1985	0	.07	0	.07	151.97	154.86	2,166	85,080
1986	0	.12	0	.12	154.29	157.45	3,565	96,207
1987	0	.19	0	.19	156.57	160.32	5,605	114,934
1988	0	.29	0	.29	158.97	162.96	8,432	126,757
1989	0	.41	0	.41	161.23	165.77	12,172	142,957
1990	0	.57	0	.57	163.73	168.53	16,914	157,369
1991	0	.76	.01	.77	166.13	171.58	22,732	179,873
1992	0	.99	.01	1.01	168.74	174.40	29,705	195,117
1993	.01	1.25	.03	1.29	171.39	177.90	37,973	229,971
1994	.03	1.55	.04	1.62	173.94	181.32	47,757	262,031
1995	.08	1.87	.07	2.02	176.73	184.78	59,378	294,889
1996	.18	2.23	.11	2.49	179.56	188.28	73,234	328,569
1997	.29	2.60	.16	3.05	182.48	191.84	89,749	363,081
1998	.49	3.00	.22	3.71	185.54	195.28	109,262	394,502
1999	.78	3.40	.30	4.48	188.73	198.78	131,970	426,665
2000	1.15	3.81	.40	5.36	192.10	202.30	157,828	459,556

[1] In 1958 dollars.

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Appendix table 1--Northeast: Scenario 1, Projected agricultural productivity, 1980 to 2000

Year	Projected productivity indexes: Mean	Standard deviation	Maximum	Minimum	Research and extension expenditures 1/	Education index
	1967=100				1,000 dollars	
1980	114.70	2.31	121.27	107.94	41,252	176.08
1981	115.67	2.43	122.25	109.43	41,252	178.44
1982	117.28	2.54	122.27	110.29	41,252	180.81
1983	118.55	2.68	124.85	111.86	41,252	183.18
1984	119.48	2.45	125.50	113.80	41,252	185.57
1985	121.12	2.66	128.48	114.76	41,252	187.96
1986	122.30	2.81	130.14	114.00	41,252	190.36
1987	123.25	2.67	129.43	116.21	41,252	192.76
1988	124.60	2.85	131.58	117.29	41,252	195.17
1989	125.75	2.69	132.89	119.21	41,252	197.58
1990	126.91	2.54	133.13	121.53	41,252	200.00
1991	128.15	2.58	133.87	122.06	41,252	202.42
1992	129.18	2.78	137.53	122.27	41,252	204.84
1993	130.64	2.73	138.91	124.54	41,252	207.26
1994	132.04	2.56	138.66	124.91	41,252	209.69
1995	133.01	2.90	140.47	126.12	41,252	212.12
1996	134.11	2.88	143.08	126.06	41,252	214.54
1997	135.31	2.93	143.47	127.74	41,252	216.97
1998	136.65	2.99	144.04	130.32	41,252	219.39
1999	138.04	2.75	144.88	131.29	41,252	221.81
2000	138.92	3.10	145.25	130.51	41,252	224.23

1/ In 1958 dollars.

Appendix table 2--Northeast: Scenario 2, Projected agricultural productivity, 1980 to 2000

Year	Projected productivity indexes: Mean	Standard deviation	Maximum	Minimum	Research and extension expenditures 1/	Education index
	1967=100				1,000 dollars	
1980	114.84	2.31	121.42	108.07	49,257	176.08
1981	115.88	2.43	122.46	109.62	50,734	178.44
1982	117.56	2.55	122.57	110.56	52,256	180.81
1983	118.93	2.68	125.24	112.21	53,824	183.18
1984	119.96	2.46	126.00	114.26	55,439	185.57
1985	121.71	2.68	129.11	115.32	57,102	187.96
1986	123.02	2.83	130.90	114.68	58,815	190.36
1987	124.10	2.69	130.32	117.01	60,580	192.76
1988	125.58	2.87	132.62	118.22	62,397	195.17
1989	126.87	2.71	134.08	120.28	64,269	197.58
1990	128.18	2.56	134.46	122.74	66,197	200.00
1991	129.56	2.60	135.34	123.40	68,183	202.42
1992	130.73	2.81	139.18	123.73	70,228	204.84
1993	132.35	2.76	140.72	126.16	72,335	207.26
1994	133.89	2.60	140.61	126.66	74,505	209.69
1995	135.02	2.95	142.59	128.02	76,740	212.12
1996	136.28	2.93	145.39	128.09	79,043	214.54
1997	137.63	2.98	145.94	129.94	81,414	216.97
1998	139.13	3.05	146.66	132.69	83,856	219.39
1999	140.69	2.81	146.67	133.81	86,372	221.81
2000	141.73	3.16	148.19	133.16	88,963	224.23

1/ In 1958 dollars.

Appendix table 3--Northeast: Scenario 3, Projected agricultural productivity, 1980 to 2000

Year	Projected productivity indexes				Research and extension expenditures 1/	Education index
	Mean	Standard deviation	Maximum	Minimum		
	1967=100				1,000 dollars	
1980	115.02	2.32	121.61	108.24	61,908	176.08
1981	116.14	2.44	122.74	109.87	66,241	178.44
1982	117.93	2.55	122.95	110.90	70,878	180.81
1983	119.41	2.70	125.75	112.67	75,840	183.18
1984	120.58	2.47	126.65	114.85	81,148	185.57
1985	122.49	2.69	129.94	116.06	86,829	187.96
1986	123.95	2.85	131.90	115.55	92,907	190.36
1987	125.20	2.71	131.47	118.05	99,410	192.76
1988	126.87	2.90	133.97	119.42	106,369	195.17
1989	128.34	2.74	135.63	121.66	113,815	197.58
1990	129.82	2.60	136.19	124.31	121,782	200.00
1991	131.39	2.64	137.26	125.14	130,307	202.42
1992	132.76	2.86	141.34	125.65	139,428	204.84
1993	134.58	2.81	143.09	128.28	149,188	207.26
1994	136.33	2.64	143.16	128.96	159,631	209.69
1995	137.65	3.00	145.37	130.52	170,805	212.12
1996	139.12	2.99	148.42	130.76	182,762	214.54
1997	140.68	3.04	149.17	132.82	195,555	216.97
1998	142.40	3.12	150.10	135.81	209,244	219.39
1999	144.19	2.88	151.34	137.14	223,891	221.81
2000	145.45	3.24	152.08	136.64	239,563	224.23

1/ In 1958 dollars.

Appendix table 4--Lake States: Scenario 1, Projected agricultural productivity, 1980 to 2000

Year	Projected productivity indexes: Mean	Standard deviation	Maximum	Minimum	Research and extension expenditures 1/	Education index
	1967=100				1,000 dollars	
1980	113.77	1.15	116.69	110.93	32,476	176.08
1981	114.99	1.14	117.97	112.28	32,476	178.44
1982	116.33	1.22	120.37	113.27	32,476	180.81
1983	117.54	1.36	120.59	113.82	32,476	183.18
1984	118.84	1.28	121.80	114.86	32,476	185.57
1985	120.10	1.25	124.39	117.03	32,476	187.96
1986	121.08	1.29	124.15	117.97	32,476	190.36
1987	122.47	1.27	125.33	119.11	32,476	192.76
1988	123.59	1.21	126.82	119.98	32,476	195.17
1989	124.84	1.30	127.90	120.62	32,476	197.58
1990	126.01	1.39	129.56	122.64	32,476	200.00
1991	127.27	1.43	130.94	123.40	32,476	202.42
1992	128.52	1.43	132.43	123.78	32,476	204.84
1993	129.57	1.25	133.09	125.61	32,476	207.26
1994	130.78	1.36	134.72	127.09	32,476	209.69
1995	132.04	1.35	136.00	128.51	32,476	212.12
1996	133.21	1.44	137.05	128.67	32,476	214.54
1997	134.33	1.33	138.35	130.58	32,476	216.97
1998	135.64	1.45	139.38	132.18	32,476	219.39
1999	136.82	1.40	141.58	133.50	32,476	221.81
2000	137.85	1.50	141.75	133.03	32,476	224.23

1/ In 1958 dollars.

Appendix table 5--Lake States: Scenario 2, Projected agricultural productivity, 1980 to 2000

Year	Projected productivity indexes				Research and extension expenditures 1/	Education index
	Mean	Standard deviation	Maximum	Minimum		
	1967=100				1,000 dollars	
1980	113.96	1.15	116.88	111.11	38,778	176.08
1981	115.26	1.14	118.25	112.55	39.941	178.44
1982	116.71	1.23	120.76	113.64	41,140	180.81
1983	118.05	1.37	121.11	114.31	42,374	183.18
1984	119.49	1.28	122.47	115.49	43,645	185.57
1985	120.92	1.26	125.24	117.83	44,954	187.96
1986	122.08	1.30	125.17	118.95	46,303	190.36
1987	123.67	1.28	126.56	120.28	47,692	192.76
1988	125.00	1.23	128.27	121.35	49,123	195.17
1989	126.47	1.32	129.57	122.20	50,597	197.58
1990	127.87	1.41	131.47	124.44	52,114	200.00
1991	129.36	1.45	133.09	125.42	53,678	202.42
1992	130.84	1.46	134.81	126.01	55,288	204.84
1993	132.12	1.28	135.71	128.09	56,947	207.26
1994	133.57	1.39	137.60	129.81	58,655	209.69
1995	135.08	1.38	139.13	131.47	60,415	212.12
1996	136.50	1.48	140.43	131.84	62,227	214.54
1997	137.87	1.36	142.00	134.02	64,094	216.97
1998	139.44	1.49	143.29	135.89	66,017	219.39
1999	140.88	1.44	145.78	137.47	67,998	221.81
2000	142.17	1.55	146.20	137.21	70,037	224.23

1/ In 1958 dollars.

Appendix table 6--Lake States: Scenario 3, Projected agricultural productivity, 1980 to 2000

Year	Projected productivity indexes				Research and extension expenditures 1/	Education index
	Mean	Standard deviation	Maximum	Minimum		
	1967=100				1,000 dollars	
1980	114.20	1.15	117.13	111.35	48,738	176.08
1981	115.62	1.15	118.61	112.89	52,149	178.44
1982	117.21	1.23	121.27	114.12	55,800	180.81
1983	118.71	1.38	121.79	114.94	59,706	183.18
1984	120.34	1.29	123.34	116.31	63,885	185.57
1985	121.99	1.27	126.34	118.87	68,357	187.96
1986	123.39	1.32	126.51	120.22	73,142	190.36
1987	125.24	1.30	128.16	121.80	78,262	192.76
1988	126.84	1.25	130.16	123.14	83,741	195.17
1989	128.61	1.34	131.76	124.26	89,602	197.58
1990	130.30	1.44	133.97	126.81	95,875	200.00
1991	132.10	1.48	135.90	128.07	102,586	202.42
1992	133.89	1.49	137.96	128.95	109,767	204.84
1993	135.49	1.31	139.16	131.35	117,450	207.26
1994	137.26	1.43	141.40	133.39	125,672	209.69
1995	139.10	1.42	143.28	135.38	134,469	212.12
1996	140.86	1.52	144.92	136.05	143,882	214.54
1997	142.57	1.41	146.84	138.59	153,953	216.97
1998	144.50	1.55	148.49	140.82	164,730	219.39
1999	146.30	1.50	151.39	142.76	176,261	221.81
2000	147.95	1.61	152.14	142.79	188,600	224.23

1/ In 1958 dollars.

Appendix table 8--Corn Belt: Scenario 2, Projected agricultural productivity, 1980 to 2000

Year	Projected productivity indexes: Mean	Standard deviation	Maximum	Minimum	Research and extension expenditures 1/	Education index
	1967=100				1,000 dollars	
1980	109.43	4.76	121.08	96.84	58,981	176.08
1981	111.39	4.57	124.70	99.96	60,751	178.44
1982	111.85	4.58	123.07	99.71	62,573	180.81
1983	113.56	4.59	124.00	99.15	64,450	183.18
1984	115.20	4.87	131.15	102.38	66,384	185.57
1985	116.45	4.71	130.03	104.01	68,375	187.96
1986	116.88	4.61	126.90	104.87	70,427	190.36
1987	118.57	4.84	132.41	106.44	72,539	192.76
1988	120.13	5.22	132.88	105.75	74,716	195.17
1989	121.09	4.75	133.30	109.46	76,957	197.58
1990	122.68	5.43	143.39	110.19	79,266	200.00
1991	123.17	5.06	138.72	110.69	81,644	202.42
1992	124.56	5.19	137.36	112.37	84,093	204.84
1993	126.72	5.36	141.14	113.95	86,616	207.26
1994	127.44	5.09	139.93	115.95	89,214	209.69
1995	128.53	5.41	143.61	115.29	91,891	212.12
1996	129.94	5.46	145.98	116.53	94,648	214.54
1997	131.48	5.49	150.26	118.94	97,487	216.97
1998	132.68	5.36	148.58	118.30	100,412	219.39
1999	134.15	5.49	148.68	115.56	103,424	221.81
2000	135.44	5.65	149.85	120.22	106,527	224.23

1/ In 1958 dollars.

Appendix table 9--Corn Belt: Scenario 3, Projected agricultural productivity, 1980 to 2000

Year	Projected productivity indexes				Research and extension expenditures 1/	Education index
	Mean	Standard deviation	Maximum	Minimum		
	1967=100				1,000 dollars	
1980	109.56	4.76	121.23	96.95	74,130	176.08
1981	111.59	4.58	124.92	100.13	79,319	178.44
1982	112.11	4.59	123.36	99.95	84,871	180.81
1983	113.91	4.61	124.39	99.46	90,812	183.18
1984	115.65	4.89	131.67	102.79	97,169	185.57
1985	117.02	4.73	130.67	104.52	103,971	187.96
1986	117.57	4.64	127.64	105.49	111,249	190.36
1987	119.39	4.87	133.33	107.18	119,036	192.76
1988	121.09	5.26	133.95	106.60	127,369	195.17
1989	122.19	4.80	134.52	110.46	136,285	197.58
1990	123.92	5.48	144.84	111.31	145,825	200.00
1991	124.56	5.12	140.28	111.94	156,032	202.42
1992	126.09	5.25	139.05	113.75	166,955	204.84
1993	128.42	5.43	143.03	115.48	178,641	207.26
1994	129.29	5.16	141.95	117.63	191,146	209.69
1995	130.53	5.49	145.85	117.09	204,527	212.12
1996	132.11	5.55	148.42	118.48	218,843	214.54
1997	133.81	5.58	152.93	121.06	234,162	216.97
1998	135.18	5.46	151.38	120.53	250,554	219.39
1999	136.82	5.60	151.64	117.87	268,093	221.81
2000	138.29	5.77	153.00	122.75	286,859	224.23

1/ In 1958 dollars.

Appendix table 10--Northern Plains: Scenario 1, Projected agricultural productivity, 1980 to 2000

Year	Projected productivity indexes: Mean	Standard deviation	Maximum	Minimum	Research and extension expenditures 1/	Education index
	1967=100				1,000 dollars	
1980	111.29	8.87	133.17	91.46	28,250	176.08
1981	113.49	8.02	130.84	93.57	28,250	178.44
1982	114.34	8.58	143.38	93.14	28,250	180.81
1983	115.78	9.08	143.39	88.42	28,250	183.18
1984	117.12	8.71	148.89	90.90	28,250	185.57
1985	118.01	9.08	138.68	93.17	28,250	187.96
1986	120.10	8.99	141.64	96.52	28,250	190.36
1987	119.52	8.63	143.08	96.83	28,250	192.76
1988	122.13	9.59	146.14	96.51	28,250	195.17
1989	122.69	10.45	148.91	96.76	28,250	197.58
1990	123.69	10.27	154.06	102.14	28,250	200.00
1991	125.10	9.64	150.93	102.71	28,250	202.42
1992	125.97	9.38	150.96	101.80	28,250	204.84
1993	127.48	9.92	154.77	104.71	28,250	207.26
1994	128.22	10.23	163.69	102.72	28,250	209.69
1995	130.31	10.15	156.19	107.94	28,250	212.12
1996	130.20	10.17	158.32	105.08	28,250	214.54
1997	132.27	10.30	163.40	110.26	28,250	216.97
1998	134.54	11.43	166.94	103.21	28,250	219.39
1999	135.28	10.67	164.82	102.21	28,250	221.81
2000	134.66	10.55	163.81	108.34	28,250	224.23

1/ In 1958 dollars.

Appendix table 11--Northern Plains: Scenario 2, Projected agricultural productivity, 1980 to 2000

Year	Projected productivity indexes: Mean	Standard deviation	Maximum	Minimum	Research and extension expenditures 1/	Education index
	1967=100				1,000 dollars	
1980	111.39	8.88	133.29	91.54	33,732	176.08
1981	113.64	8.03	131.01	93.69	34,744	178.44
1982	114.54	8.60	143.63	93.30	35,786	180.81
1983	116.04	9.10	143.72	88.63	36,860	183.18
1984	117.46	8.74	149.32	91.16	37,966	185.57
1985	118.43	9.11	139.17	93.50	39,105	187.96
1986	120.61	9.02	142.24	96.93	40,278	190.36
1987	120.11	8.67	143.78	97.31	41,486	192.76
1988	122.82	9.65	146.96	97.06	42,731	195.17
1989	123.46	10.52	149.85	97.38	44,013	197.58
1990	124.56	10.34	155.15	102.86	45,333	200.00
1991	126.07	9.71	152.10	103.50	46,693	202.42
1992	127.04	9.46	152.24	102.67	48,094	204.84
1993	128.65	10.01	156.19	105.67	49,537	207.26
1994	129.48	10.33	165.31	103.74	51,023	209.69
1995	131.69	10.26	157.85	109.08	52,553	212.12
1996	131.67	10.28	160.11	106.27	54,130	214.54
1997	133.86	10.43	165.36	111.59	55,754	216.97
1998	136.25	11.57	169.06	104.52	57,426	219.39
1999	137.10	10.81	167.03	103.59	59,149	221.81
2000	136.57	10.70	166.13	109.87	60,924	224.23

1/ In 1958 dollars.

Appendix table 12--Northern Plains: Scenario 3, Projected agricultural productivity, 1980 to 2000

Year	Projected productivity indexes: Mean	Projected productivity indexes: Standard deviation	Projected productivity indexes: Maximum	Projected productivity indexes: Minimum	Research and extension expenditures 1/	Education index
	1967=100				1,000 dollars	
1980	111.52	8.89	133.45	91.64	42,396	176.08
1981	113.83	8.04	131.23	93.84	45,363	178.44
1982	114.80	8.62	143.95	93.51	48,539	180.81
1983	116.39	9.13	144.14	88.89	51,936	183.18
1984	117.90	8.77	149.88	91.50	55,572	185.57
1985	118.97	9.16	139.80	93.93	59,462	187.96
1986	121.27	9.07	143.02	97.46	63,624	190.36
1987	120.87	8.72	144.70	97.93	68,078	192.76
1988	123.71	9.72	148.03	97.76	72,844	195.17
1989	124.47	10.60	151.08	98.17	77,943	197.58
1990	125.70	10.44	156.56	103.80	83,399	200.00
1991	127.33	9.81	153.62	104.54	89,236	202.42
1992	128.43	9.56	153.91	103.79	95,483	204.84
1993	130.17	10.13	158.04	106.92	102,167	207.26
1994	131.14	10.46	167.42	105.06	109,318	209.69
1995	133.49	10.40	160.00	110.58	116,971	212.12
1996	133.59	10.43	162.45	107.82	125,159	214.54
1997	135.93	10.59	167.93	113.32	133,920	216.97
1998	138.49	11.76	171.84	106.24	143,294	219.39
1999	139.48	11.00	169.93	105.38	153,325	221.81
2000	139.07	10.90	169.16	111.88	164,058	224.23

1/ In 1958 dollars.

Appendix table 13--Appalachian: Scenario 1, Projected agricultural productivity, 1980 to 2000

Year	Projected productivity indexes				Research and extension expenditures 1/	Education index
	Mean	Standard deviation	Maximum	Minimum		
	1967=100				1,000 dollars	
1980	125.44	4.84	140.48	111.90	38,334	176.08
1981	127.20	4.78	143.94	113.43	38,334	178.44
1982	128.17	4.57	143.45	114.97	38,334	180.81
1983	129.63	4.77	143.80	116.88	38,334	183.18
1984	131.22	4.80	145.07	119.45	38,334	185.57
1985	132.23	4.95	146.61	118.51	38,334	187.96
1986	134.13	4.97	148.14	123.09	38,334	190.36
1987	135.11	5.03	149.58	121.99	38,334	192.76
1988	136.88	5.18	151.71	123.47	38,334	195.17
1989	136.78	4.78	150.67	124.72	38,334	197.58
1990	139.95	5.31	154.82	129.22	38,334	200.00
1991	140.39	5.02	154.89	129.32	38,334	202.42
1992	141.66	5.55	157.18	127.14	38,334	204.84
1993	143.28	5.27	157.99	128.56	38,334	207.26
1994	144.59	5.74	160.06	132.17	38,334	209.69
1995	145.15	5.26	160.96	129.40	38,334	212.12
1996	147.73	5.57	162.47	134.53	38,334	214.54
1997	148.25	5.16	164.90	133.52	38,334	216.97
1998	150.09	5.94	164.74	134.36	38,334	219.39
1999	150.15	6.31	169.85	135.16	38,334	221.81
2000	151.79	5.40	165.98	138.80	38,334	224.23

1/ In 1958 dollars.

Appendix table 14--Appalachian: Scenario 2, Projected agricultural productivity, 1980 to 2000

Year	Projected productivity indexes				Research and extension expenditures 1/	Education index
	Mean	Standard deviation	Maximum	Minimum		
	1967=100				1,000 dollars	
1980	125.62	4.84	140.68	112.07	45,772	176.08
1981	127.47	4.79	144.24	113.66	47,146	178.44
1982	128.54	4.58	143.86	115.30	48,560	180.81
1983	130.12	4.79	144.34	117.33	50,017	183.18
1984	131.85	4.82	145.77	120.02	51,517	185.57
1985	133.02	4.98	147.48	119.21	53,063	187.96
1986	135.09	5.00	149.19	123.97	54,655	190.36
1987	136.24	5.08	150.84	123.02	56,294	192.76
1988	138.21	5.23	153.18	124.67	57,983	195.17
1989	138.29	4.84	152.34	126.10	59,723	197.58
1990	141.68	5.37	156.73	130.81	61,514	200.00
1991	142.31	5.09	157.01	131.09	63,360	202.42
1992	143.78	5.64	159.54	129.04	65,261	204.84
1993	145.61	5.35	160.56	130.66	67,218	207.26
1994	147.14	5.84	162.87	134.49	69,235	209.69
1995	147.90	5.36	164.00	131.84	71,312	212.12
1996	150.72	5.68	165.76	137.25	73,451	214.54
1997	151.45	5.27	168.46	136.40	75,655	216.97
1998	153.52	6.07	168.51	137.43	77,925	219.39
1999	153.78	6.46	173.96	138.43	80,262	221.81
2000	155.67	5.53	170.22	142.35	82,670	224.23

1/ In 1958 dollars.

Appendix table 15--Appalachian: Scenario 3, Projected agricultural productivity, 1980 to 2000

Year	Projected productivity indexes				Research and extension expenditures 1/	Education index
	Mean	Standard deviation	Maximum	Minimum		
	1967=100				1,000 dollars	
1980	125.86	4.85	140.95	112.28	57,529	176.08
1981	127.81	4.80	144.64	113.97	61,556	178.44
1982	129.01	4.60	144.40	115.73	65,864	180.81
1983	130.76	4.82	145.05	117.90	70,475	183.18
1984	132.67	4.85	146.67	120.77	75,408	185.57
1985	134.03	5.02	148.61	120.13	80,687	187.96
1986	136.34	5.05	150.57	125.12	86,335	190.36
1987	137.72	5.13	152.48	124.36	92,378	192.76
1988	139.95	5.30	155.11	126.24	98,845	195.17
1989	140.26	4.91	154.51	127.90	105,764	197.58
1990	143.94	5.46	159.23	132.90	113,167	200.00
1991	144.82	5.18	159.78	133.40	121,089	202.42
1992	146.56	5.75	162.62	131.53	129,565	204.84
1993	148.68	5.47	163.94	133.41	138,635	207.26
1994	150.48	5.97	166.58	137.55	148,339	209.69
1995	151.52	5.49	168.02	135.07	158,723	212.12
1996	154.66	5.83	170.09	140.85	169,834	214.54
1997	155.67	5.42	173.16	140.20	181,722	216.97
1998	158.07	6.25	173.50	141.50	194,443	219.39
1999	158.60	6.66	179.41	142.76	208,054	221.81
2000	160.82	5.72	175.85	147.05	222,618	224.23

1/ In 1958 dollars.

Appendix table 16--Southeast: Scenario 1, Projected agricultural productivity, 1980 to 2000

Year	Projected productivity indexes				Research and extension expenditures 1/	Education index
	Mean	Standard deviation	Maximum	Minimum		
	1967=100				1,000 dollars	
1980	124.09	4.89	137.23	110.78	38,928	176.08
1981	125.12	5.07	140.14	114.48	38,928	178.44
1982	126.40	5.14	140.02	110.17	38,928	180.81
1983	127.96	4.90	143.22	116.41	38,928	183.18
1984	129.01	5.06	142.42	116.03	38,928	185.57
1985	130.03	5.26	145.95	116.32	38,928	187.96
1986	131.06	5.40	147.38	119.33	38,928	190.36
1987	133.06	4.92	148.15	122.24	38,928	192.76
1988	134.19	5.54	145.99	119.79	38,928	195.17
1989	135.31	5.19	150.48	121.77	38,928	197.58
1990	137.23	5.08	149.49	120.57	38,928	200.00
1991	137.45	5.27	152.30	125.71	38,928	202.42
1992	139.23	5.13	152.71	122.99	38,928	204.84
1993	140.78	6.14	163.92	124.74	38,928	207.26
1994	141.68	5.22	153.37	128.66	38,928	209.69
1995	142.94	5.70	161.64	130.26	38,928	212.12
1996	144.42	5.55	160.85	130.62	38,928	214.54
1997	145.86	5.38	158.27	132.16	38,928	216.97
1998	147.71	6.06	164.68	132.53	38,928	219.39
1999	148.37	6.07	171.31	133.35	38,928	221.81
2000	149.97	5.80	167.90	135.31	38,928	224.23

1/ In 1958 dollars.

Appendix table 17--Southeast: Scenario 2, Projected agricultural productivity, 1980 to 2000

Year	Projected productivity indexes				Research and extension expenditures 1/	Education index
	Mean	Standard deviation	Maximum	Minimum		
	1967=100				1,000 dollars	
1980	124.24	4.90	137.40	110.91	46,482	176.08
1981	125.34	5.08	140.38	114.68	47,877	178.44
1982	126.70	5.15	140.36	110.44	49,313	180.81
1983	128.36	4.92	143.67	116.78	50,792	183.18
1984	129.53	5.08	142.98	116.50	52,316	185.57
1985	130.68	5.29	146.67	116.89	53,886	187.96
1986	131.83	5.43	148.26	120.03	55,502	190.36
1987	133.99	4.95	149.18	123.09	57,167	192.76
1988	135.27	5.59	147.17	120.76	58,882	195.17
1989	136.55	5.24	151.85	122.88	60,649	197.58
1990	138.63	5.14	151.03	121.81	62,468	200.00
1991	139.01	5.33	154.02	127.13	64,342	202.42
1992	140.95	5.19	154.60	124.52	66,272	204.84
1993	142.68	6.23	166.14	126.43	68,261	207.26
1994	143.75	5.30	155.61	130.54	70,308	209.69
1995	145.18	5.79	164.18	132.31	72,418	212.12
1996	146.85	5.64	163.55	132.81	74,590	214.54
1997	148.47	5.47	161.10	134.53	76,828	216.97
1998	150.51	6.18	167.80	135.05	79,133	219.39
1999	151.35	6.19	174.75	136.03	81,507	221.81
2000	153.15	5.92	171.45	138.17	83,952	224.23

1/ In 1958 dollars.

Appendix table 18--Southeast: Scenario 3, Projected agricultural productivity, 1980 to 2000

Year	Projected productivity indexes: Mean	Standard deviation	Maximum	Minimum	Research and extension expenditures 1/	Education index
	1967=100				1,000 dollars	
1980	124.43	4.91	137.62	111.08	58,420	176.08
1981	125.62	5.09	140.70	114.94	62,510	178.44
1982	127.09	5.17	140.79	110.78	66,886	180.81
1983	128.88	4.94	144.25	117.25	71,568	183.18
1984	130.19	5.11	143.72	117.10	76,577	185.57
1985	131.51	5.32	147.61	117.64	81,938	187.96
1986	132.84	5.47	149.39	120.95	87,673	190.36
1987	135.20	5.00	150.53	124.20	93,811	192.76
1988	136.68	5.65	148.70	122.02	100,377	195.17
1989	138.17	5.30	153.65	124.33	107,404	197.58
1990	140.47	5.20	153.02	123.42	114,922	200.00
1991	141.04	5.40	156.28	128.99	122,966	202.42
1992	143.22	5.27	157.08	126.52	131,574	204.84
1993	145.17	6.33	169.04	128.64	140,784	207.26
1994	146.46	5.40	158.55	133.00	150,639	209.69
1995	148.13	5.91	167.51	134.99	161,184	212.12
1996	150.03	5.77	167.10	135.69	172,467	214.54
1997	151.90	5.60	164.83	137.64	184,540	216.97
1998	154.20	6.33	171.92	138.36	197,457	219.39
1999	155.28	6.36	179.28	139.56	211,279	221.81
2000	157.34	6.09	176.15	141.96	226,069	224.23

1/ In 1958 dollars.

Appendix table 19--Delta States: Scenario 1, Projected agricultural productivity, 1980 to 2000

Year	Projected productivity indexes				Research and extension expenditures 1/	Education index
	Mean	Standard deviation	Maximum	Minimum		
	1967=100				1,000 dollars	
1980	120.96	5.46	137.05	105.73	29,745	176.08
1981	122.90	5.11	136.17	111.14	29,745	178.44
1982	124.91	5.35	139.47	111.70	29,745	180.81
1983	125.61	5.40	139.51	108.82	29,745	183.18
1984	126.95	5.58	142.76	113.70	29,745	185.57
1985	127.75	5.71	143.55	112.63	29,745	187.96
1986	128.70	5.96	144.54	114.35	29,745	190.36
1987	130.23	5.56	149.67	115.53	29,745	192.76
1988	131.60	5.64	145.80	118.47	29,745	195.17
1989	133.58	6.27	147.85	116.40	29,745	197.58
1990	134.05	6.05	154.55	117.06	29,745	200.00
1991	135.25	6.33	151.32	119.87	29,745	202.42
1992	136.86	6.03	157.36	120.06	29,745	204.84
1993	137.43	6.92	157.54	122.57	29,745	207.26
1994	139.22	6.20	155.08	125.37	29,745	209.69
1995	139.58	6.34	158.75	126.33	29,745	212.12
1996	141.73	6.33	158.45	126.76	29,745	214.54
1997	142.26	6.42	163.64	124.01	29,745	216.97
1998	144.28	6.55	165.54	126.18	29,745	219.39
1999	145.99	6.26	167.18	126.59	29,745	221.81
2000	146.68	6.93	165.85	128.10	29,745	224.23

1/ In 1958 dollars.

Appendix table 20--Delta States: Scenario 2, Projected agricultural productivity, 1980 to 2000

Year	Projected productivity indexes				Research and extension expenditures 1/	Education index
	Mean	Standard deviation	Maximum	Minimum		
	1967=100				1,000 dollars	
1980	121.23	5.47	137.35	105.97	35,516	176.08
1981	123.29	5.13	136.60	111.50	36,582	178.44
1982	125.44	5.37	140.06	112.18	37,679	180.81
1983	126.30	5.43	140.27	109.42	38,810	183.18
1984	127.82	5.62	143.73	114.47	39,974	185.57
1985	128.79	5.76	144.72	113.54	41,173	187.96
1986	129.93	6.02	145.91	115.44	42,409	190.36
1987	131.65	5.62	151.31	116.79	43,681	192.76
1988	133.22	5.71	147.59	119.92	44,991	195.17
1989	135.41	6.36	149.87	117.99	46,341	197.58
1990	136.07	6.14	156.88	118.82	47,731	200.00
1991	137.47	6.43	153.80	121.84	49,163	202.42
1992	139.30	6.14	160.17	122.20	50,638	204.84
1993	140.07	7.06	160.57	124.92	52,157	207.26
1994	142.09	6.33	158.27	127.95	53,722	209.69
1995	142.65	6.48	162.24	129.11	55,334	212.12
1996	145.04	6.48	162.15	129.72	56,994	214.54
1997	145.79	6.58	167.69	127.08	58,703	216.97
1998	148.06	6.72	169.87	129.48	60,464	219.39
1999	150.02	6.44	171.78	130.07	62,278	221.81
2000	150.93	7.13	170.66	131.81	64,147	224.23

1/ In 1958 dollars.

Appendix table 21--Delta States: Scenario 3, Projected agricultural productivity, 1980 to 2000

Year	Projected productivity indexes				Research and extension expenditures 1/	Education index
	Mean	Standard deviation	Maximum	Minimum		
	1967=100				1,000 dollars	
1980	121.58	5.49	137.74	106.27	44,638	176.08
1981	123.79	5.15	137.15	111.95	47,763	178.44
1982	126.13	5.40	140.83	112.79	51,107	180.81
1983	127.19	5.47	141.26	110.19	54,684	183.18
1984	128.93	5.67	144.99	115.47	58,512	185.57
1985	130.15	5.82	146.24	114.74	62,608	187.96
1986	131.53	6.10	147.71	116.86	66,990	190.36
1987	133.50	5.70	153.44	118.43	71,680	192.76
1988	135.33	5.80	149.93	121.82	76,697	195.17
1989	137.79	6.47	152.52	120.07	82,066	197.58
1990	138.71	6.26	159.93	121.13	87,811	200.00
1991	140.39	6.57	157.07	124.43	93,957	202.42
1992	142.51	6.28	163.85	125.01	100,534	204.84
1993	143.55	7.23	164.55	128.02	107,572	207.26
1994	145.87	6.50	162.49	131.36	115,102	209.69
1995	146.70	6.67	166.85	132.78	123,159	212.12
1996	149.43	6.68	167.06	133.64	131,780	214.54
1997	150.46	6.79	173.07	131.15	141,005	216.97
1998	153.07	6.94	175.62	133.87	150,875	219.39
1999	155.37	6.67	177.91	134.71	161,436	221.81
2000	156.59	7.40	177.06	136.75	172,737	224.23

1/ In 1958 dollars.

Appendix table 22--Southern Plains: Scenario 1, Projected agricultural productivity, 1980 to 2000

Year	Projected productivity indexes				Research and extension expenditures 1/	Education index
	Mean	Standard deviation	Maximum	Minimum		
	1967=100				1,000 dollars	
1980	117.68	8.64	139.09	98.10	25,758	176.08
1981	119.46	8.15	148.34	98.68	25,758	178.44
1982	120.31	8.82	143.92	100.23	25,758	180.81
1983	122.19	9.41	153.29	97.87	25,758	183.18
1984	123.09	8.93	150.73	95.78	25,758	185.57
1985	123.68	8.68	143.36	103.09	25,758	187.96
1986	125.95	8.50	148.63	106.68	25,758	190.36
1987	127.66	10.04	153.26	102.29	25,758	192.76
1988	128.61	9.33	151.17	108.62	25,758	195.17
1989	128.84	9.11	158.11	104.57	25,758	197.58
1990	130.46	9.68	157.80	104.52	25,758	200.00
1991	132.33	9.47	159.39	107.84	25,758	202.42
1992	131.81	10.40	160.98	105.34	25,758	204.84
1993	134.76	10.67	162.98	110.50	25,758	207.26
1994	135.22	10.22	164.60	110.02	25,758	209.69
1995	137.69	10.35	178.85	110.72	25,758	212.12
1996	137.27	10.40	164.72	112.80	25,758	214.54
1997	139.21	10.19	164.77	112.55	25,758	216.97
1998	140.58	11.07	171.63	116.29	25,758	219.39
1999	141.52	11.44	174.37	109.79	25,758	221.81
2000	142.82	10.01	171.91	116.94	25,758	224.23

1/ In 1958 dollars.

Appendix table 23--Southern Plains: Scenario 2, Projected agricultural productivity, 1980 to 2000

Year	Projected productivity indexes				Research and extension expenditures 1/	Education index
	Mean	Standard deviation	Maximum	Minimum		
	1967=100				1,000 dollars	
1980	117.76	8.65	139.19	98.17	30,756	176.08
1981	119.58	8.16	148.49	98.78	31,679	178.44
1982	120.48	8.83	144.12	100.37	32,629	180.81
1983	122.42	9.43	153.57	98.05	33,608	183.18
1984	123.37	8.95	151.08	96.01	34,616	185.57
1985	124.03	8.71	143.77	103.38	35,655	187.96
1986	126.38	8.53	149.14	107.05	36,724	190.36
1987	128.17	10.08	153,88	102.71	37,826	192.76
1988	129.21	9.37	151.87	109.12	38,961	195.17
1989	129.53	9.16	158.95	105.12	40,130	197.58
1990	131.23	9.74	158.73	105.14	41,333	200.00
1991	133.20	9.54	160.43	108.55	42,573	202.42
1992	132.76	10.48	162.14	106.10	43,851	204.84
1993	135.81	10.75	164.26	111.37	45,166	207.26
1994	136.36	10.31	165.99	110.95	46,521	209.69
1995	138.94	10.44	180.48	111.72	47,917	212.12
1996	138.61	10.50	166.32	113.89	49,354	214.54
1997	140.65	10.29	166.48	113.72	50,835	216.97
1998	142.13	11.19	173.51	117.56	52,360	219.39
1999	143.16	11.57	176.40	111.06	53,931	221.81
2000	144.56	10.13	174.01	118.37	55,549	224.23

1/ In 1958 dollars.

Appendix table 24--Southern Plains: Scenario 2, Projected agricultural productivity, 1980 to 2000

Year	Projected productivity indexes				Research and extension expenditures 1/	Education index
	Mean	Standard deviation	Maximum	Minimum		
	1967=100				1,000 dollars	
1980	117.87	8.66	139.31	98.26	38,655	176.08
1981	119.74	8.17	148.69	98.91	41,361	178.44
1982	120.69	8.85	144.38	100.54	44,256	180.81
1983	122.70	9.45	153.93	98.28	47,354	183.18
1984	123.74	8.98	151.53	96.29	50,669	185.57
1985	124.49	8.74	144.30	103.76	54,216	187.96
1986	126.94	8.56	149.80	107.52	58,011	190.36
1987	128.84	10.13	154.69	103.25	62,072	192.76
1988	129.99	9.43	152.79	109.78	66,417	195.17
1989	130.41	9.22	160.03	105.84	71,066	197.58
1990	132.24	9.81	159.95	105.94	76,041	200.00
1991	134.32	9.62	161.79	109.47	81,364	202.42
1992	133.99	10.57	163.64	107.08	87,059	204.84
1993	137.18	10.86	165.92	112.49	93,153	207.26
1994	137.84	10.42	167.80	112.16	99,674	209.69
1995	140.56	10.56	182.59	113.03	106,651	212.12
1996	140.34	10.63	168.40	115.32	114,117	214.54
1997	142.53	10.43	168.70	115.23	122,105	216.97
1998	144.14	11.35	175.97	119.23	130,652	219.39
1999	145.31	11.75	179.04	112.73	139,798	221.81
2000	146.85	10.29	176.76	120.24	149,584	224.23

1/ In 1958 dollars.

Appendix table 25--Mountain: Scenario 1, Projected agricultural productivity, 1980 to 2000

Year	Projected productivity indexes				Research and extension expenditures 1/	Education index
	Mean	Standard deviation	Maximum	Minimum		
	1967=100				1,000 dollars	
1980	119.59	1.99	124.95	114.62	36,818	176.08
1981	120.57	1.89	126.61	114.36	36,818	178.44
1982	121.85	1.99	127.35	116.04	36,818	180.81
1983	123.25	2.02	128.64	117.20	36,818	183.18
1984	124.23	2.04	129.87	119.76	36,818	185.57
1985	125.43	1.97	129.78	120.19	36,818	187.96
1986	126.94	2.09	132.25	122.44	36,818	190.36
1987	128.18	2.04	134.73	122.20	36,818	192.76
1988	129.37	2.13	135.10	124.02	36,818	195.17
1989	130.82	2.24	137.00	124.11	36,818	197.58
1990	131.71	2.03	136.71	125.33	36,818	200.00
1991	133.38	2.15	138.63	128.10	36,818	202.42
1992	134.46	2.14	141.75	129.52	36,818	204.84
1993	135.76	2.10	142.27	130.75	36,818	207.26
1994	136.77	2.12	143.05	130.56	36,818	209.69
1995	138.07	2.37	145.15	132.95	36,818	212.12
1996	139.47	2.35	147.40	133.82	36,818	214.54
1997	140.54	2.27	146.69	134.80	36,818	216.97
1998	142.05	2.32	148.61	136.27	36,818	219.39
1999	143.24	2.34	148.66	137.08	36,818	221.81
2000	144.35	2.39	151.80	138.52	36,818	224.23

1/ In 1958 dollars.

Appendix table 26--Mountain: Scenario 2, Projected agricultural productivity, 1980 to 2000

Year	Projected productivity indexes				Research and extension expenditures 1/	Education index
	Mean	Standard deviation	Maximum	Minimum		
	1967=100				1,000 dollars	
1980	119.86	2.00	125.24	114.88	43,963	176.08
1981	120.96	1.90	127.01	114.73	45,282	178.44
1982	122.38	2.00	127.90	116.54	46,641	180.81
1983	123.93	2.03	129.36	117.85	48,040	183.18
1984	125.09	2.05	130.77	120.59	49,481	185.57
1985	126.47	1.99	130.86	121.19	50,965	187.96
1986	128.17	2.11	133.54	123.63	52,494	190.36
1987	129.61	2.06	136.23	123.56	54,069	192.76
1988	130.99	2.16	136.79	125.57	55,691	195.17
1989	132.63	2.27	138.90	125.84	57,362	197.58
1990	133.73	2.06	138.81	127.25	59,083	200.00
1991	135.61	2.18	140.95	130.24	60,855	202.42
1992	136.89	2.18	144.32	131.87	62,681	204.84
1993	138.41	2.14	145.06	133.31	64,561	207.26
1994	139.64	2.16	146.05	133.29	66,498	209.69
1995	141.16	2.42	148.40	135.93	68,493	212.12
1996	142.79	2.40	150.91	137.00	70,548	214.54
1997	144.09	2.33	150.39	138.20	72,664	216.97
1998	145.83	2.38	152.57	139.91	74,844	219.39
1999	147.26	2.41	152.84	140.93	77,090	221.81
2000	148.61	2.46	156.28	142.61	79,402	224.23

1/ In 1958 dollars.

Appendix table 27--Mountain: Scenario 3, Projected agricultural productivity, 1980 to 2000

Year	Projected productivity indexes				Research and extension expenditures 1/	Education index
	Mean	Standard deviation	Maximum	Minimum		
	1967=100				1,000 dollars	
1980	120.21	2.00	125.60	115.22	55,255	176.08
1981	121.46	1.91	127.54	115.20	59,122	178.44
1982	123.06	2.01	128.62	117.19	63,261	180.81
1983	124.82	2.05	130.29	118.70	67,689	183.18
1984	126.20	2.07	131.94	121.66	72,428	185.57
1985	127.83	2.01	132.26	122.49	77,497	187.96
1986	129.78	2.14	135.21	125.18	82,922	190.36
1987	131.46	2.09	138.18	125.33	88,727	192.76
1988	133.10	2.19	139.00	127.60	94,938	195.17
1989	135.02	2.31	141.40	128.10	101,583	197.58
1990	136.38	2.10	141.55	129.76	108,694	200.00
1991	138.54	2.23	144.00	133.05	116,303	202.42
1992	140.10	2.23	147.70	134.96	124,444	204.84
1993	141.91	2.19	148.72	136.68	133,155	207.26
1994	143.43	2.22	150.01	136.90	142,476	209.69
1995	145.24	2.49	152.69	139.86	152,449	212.12
1996	147.18	2.48	155.55	141.22	163,121	214.54
1997	148.79	2.41	155.30	142.71	174,539	216.97
1998	150.86	2.46	157.82	144.73	186,757	219.39
1999	152.61	2.50	158.39	146.05	199,830	221.81
2000	154.28	2.56	162.25	148.05	213,818	224.23

1/ In 1958 dollars.

Appendix table 28--Pacific: Scenario 1, Projected agricultural productivity, 1980 to 2000

Year	Projected productivity indexes: Mean	Standard deviation	Maximum	Minimum	Research and extension expenditures 1/	Education index
	1967=100				1,000 dollars	
1980	140.17	.48	141.24	138.49	48,548	176.08
1981	141.67	.50	142.95	140.03	48,548	178.44
1982	143.23	.46	144.91	141.88	48,548	180.81
1983	144.70	.49	146.07	143.35	48,548	183.18
1984	146.16	.49	147.74	145.00	48,548	185.57
1985	147.57	.50	149.10	146.36	48,548	187.96
1986	149.10	.48	150.63	147.81	48,548	190.36
1987	150.57	.51	151.98	149.19	48,548	192.76
1988	152.10	.52	153.81	150.46	48,548	195.17
1989	153.46	.51	155.08	151.90	48,548	197.58
1990	155.00	.53	156.44	153.74	48,548	200.00
1991	156.39	.54	157.89	154.80	48,548	202.42
1992	157.92	.51	159.05	156.54	48,548	204.84
1993	159.43	.48	160.76	158.26	48,548	207.26
1994	160.79	.51	162.40	159.50	48,548	209.69
1995	162.29	.57	163.66	160.97	48,548	212.12
1996	163.74	.51	165.07	162.31	48,548	214.54
1997	165.19	.50	166.57	163.82	48,548	216.97
1998	166.65	.57	168.08	165.33	48,548	219.39
1999	168.11	.53	169.53	166.83	48,548	221.81
2000	169.63	.56	171.17	168.12	48,548	224.23

1/ In 1958 dollars.

Appendix table 29--Pacific: Scenario 2, Projected agricultural productivity, 1980 to 2000

Year	Projected productivity indexes: Mean	Standard deviation	Maximum	Minimum	Research and extension expenditures 1/	Education index
	1967=100				1,000 dollars	
1980	140.68	.48	141.75	139.00	57,969	176.08
1981	142.40	.50	143.69	140.75	59,708	178.44
1982	144.22	.46	145.91	142.85	61,499	180.81
1983	145.96	.50	147.35	144.60	63,344	183.18
1984	147.73	.50	149.33	146.55	65,244	185.57
1985	149.45	.50	151.00	148.22	67,202	187.96
1986	151.29	.49	152.85	149.99	69,218	190.36
1987	153.08	.52	154.52	151.68	71,294	192.76
1988	154.94	.53	156.68	153.27	73,433	195.17
1989	156.64	.52	158.28	155.04	75,636	197.58
1990	158.51	.54	159.99	157.22	77,905	200.00
1991	160.25	.55	161.79	158.62	80,242	202.42
1992	162.13	.52	163.30	160.72	82,650	204.84
1993	164.00	.50	165.37	162.80	85,129	207.26
1994	165.73	.52	167.39	164.39	87,683	209.69
1995	167.60	.59	169.02	166.24	90,314	212.12
1996	169.44	.53	170.81	167.95	93,023	214.54
1997	171.27	.52	172.70	169.84	95,814	216.97
1998	173.12	.59	174.61	171.75	98,688	219.39
1999	174.98	.55	176.46	173.65	101,649	221.81
2000	176.90	.59	178.51	175.33	104,698	224.23

1/ In 1958 dollars.

Appendix table 30--Pacific: Scenario 3, Projected agricultural productivity, 1980 to 2000

Year	Projected productivity indexes: Mean	Standard deviation	Maximum	Minimum	Research and extension expenditures 1/	Education index
	1967=100				1,000 dollars	
1980	141.35	.48	142.42	139.65	72,857	176.08
1981	143.35	.51	144.65	141.69	77,958	178.44
1982	145.50	.47	147.20	144.12	83,415	180.81
1983	147.61	.50	149.01	146.24	89,254	183.18
1984	149.77	.50	151.40	148.59	95,501	185.57
1985	151.90	.51	153.48	150.65	102,186	187.96
1986	154.17	.50	155.75	152.84	109,339	190.36
1987	156.38	.53	157.85	154.95	116,993	192.76
1988	158.68	.54	160.47	156.97	125,183	195.17
1989	160.82	.53	162.51	159.18	133,946	197.58
1990	163.16	.56	164.68	161.83	143,322	200.00
1991	165.36	.57	166.95	163.68	153,354	202.42
1992	167.73	.54	168.94	166.27	164,089	204.84
1993	170.10	.52	171.51	168.85	175,575	207.26
1994	172.32	.54	174.04	170.93	187,866	209.69
1995	174.71	.61	176.18	173.28	201,016	212.12
1996	177.07	.56	178.50	175.51	215,087	214.54
1997	179.43	.54	180.93	177.94	230,143	216.97
1998	181.83	.62	183.39	180.39	246,253	219.39
1999	184.25	.58	185.80	182.85	263,491	221.81
2000	186.74	.62	188.44	185.09	281,936	224.23

1/ In 1958 dollars.