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AGRICULTURAL RESEARCH AND THE FUTURE OF AMERICAN AGRICULTURE

by

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AGRICULTURAL RESEARCH AND THE FUTURE OF AMERICAN AGRICULTURE

by

VERNON W. RUTTAN*

INTRODUCTION

Prior to this century, almost all of the increase in world agricultural production was obtained by expanding the area cultivated -- by bringing new land into production. There were only a few exceptions to this generalization, in limited areas in East Asia, in the Middle East, and in Western Europe. By the end of this century, almost all of the increases in agricultural production must come from higher yields, from increased output per hectare.

In most arenas of the world, the transition from a resource-based to a science-based system of agriculture is occurring within a single century. In a few countries, including the U.S., this transition began in the 19th century. In most of the presently developed countries, it did not begin until the first half of this century. Most of the countries of the developing world have been caught up in the transition only since mid-century.

In most developing countries, the institutional capacity to generate rates of growth in agricultural productivity consistent with modern rates

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of growth in the demand for agricultural poroducts has not yet been fully established. In the developed countries, concern has shifted from the capacity to sustain growth in production to a concern with the design of policies and institutions to manage more effectively the use of agricultural technology.

In this paper I first review the sources that have accounted for growth of agricultural production in the past. I then examine the more recent evidence on the contribution of research to growth in agricultural production. Finally, I present some of my own perspectives on issues related to the support for agricultural research and the focus of agricultural research effort over the next several decades.

SOURCES OF GROWTH IN AGRICULTURAL PRODUCTION[1]

During the remaining years of the 20th century, it is imperative that both the rich and the poor countries design and implement more effective policies to assure the growth of agricultural production. A useful first step in thinking about this problem is to review the approaches to agricultural development that have been employed in the past and that will remain part of our intellectual equipment.

The literature on agricultural development can be characterized as offering a half-dozen distinct explanations or "models" of agricultural development:

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[1]This section draws primarily on material originally presented in Hayami and Ruttan (1971). It has been revised and edited in several more recent publications (Ruttan, 1977; Binswanger and Ruttan, 1978; Yamada and Ruttan, 1980; Ruttan, Binswanger and Hayami, 1980).

a. the frontier model

b. the conservation model

c. the urban industrial impact model

d. the diffusion model

e. the high-payoff input model

f. the induced innovation model.

These models should not be interpreted as sequential stages in agricultural development. Rather they describe approaches that have been and continue to be pursued, singly or in combination, to achieve increases in agricultural production.

THE FRONTIER MODEL

Throughout most of history, expansion of the area cultivated or grazed has represented the dominant source of increase in agricultural production. The most dramatic example in Western history was the opening up of the new continents -- North and South American and Australia -- to European settlement during the 18th and 19th centuries. With the advent of cheap transport during the latter half of the 19th century, the countries of the new continents became increasingly important sources of food and agricultural raw materials for the metropolitan countries of Western Europe.

In the United States the potential for expansion of agricultural production by bringing new lands under cultivation was largely completed by the beginning of the 20th century. The 1970s saw the "closing of the frontier" in most areas of Southeast Asia. In Latin American and Africa, the opening up of new lands awaits the development of technologies for controlling pests and diseases (such as the tsetse fly in Africa) or for releasing and maintaining the productivity of problem soils. By the end of this century, there will be few areas in the world where development along the lines of the frontier model will represent an efficient source of growth in agricultural production.

THE CONSERVATION MODEL

The conservation model of agricultural development evolved from the advances in crop and livestock husbandry associated with the English agricultural revolution and the notions of soil exhaustion suggested by the early German chemists and soil scientists. Until well into the 20th century, the conservation model of agricultural development was the only approach to intensification of agricultural production that was available to most of the world's farmers.

The conservation model emphasized the evolution of a sequence of increasingly complex land and labor-intensive cropping systems, the production and use of organic manures, and labor-intensive capital formation in the form of drainage, irrigation, and other physical facilities to utilize land and water resources more effectively. The inputs used in the conservation system of farming -- the plant nutrients, the animal power, land improvements, physical capital, and the agricultural labor force -- were largely produced or supplied by the agricultural sector itself. Efforts to transplant the conservation model of agricultural development to the United States during the 19th century were largely frustrated by the high cost of labor and the low price of land. Initial success during the early decades of the 20th century were reversed after 1940 by the sharp decline in the costs of energy used to produce machines, fuel, fertilizer, and pesticides.

The most serious effort to develop agriculture within the perspective of the conservation model in recent history was made by the People's Republic of China in the late 1950s and early 1960s. It became readily apparent, however, that the feasible growth rates even under a rigorous recycling effort were not compatible with modern growth rates in the demand for agricultural output, which typically fall in the 3 to 5 percent range in most less developed countries (LDCs). The conservation model remains an important source of productivity growth in most poor countries and an inspiration to agrarian fundamentalists and the organic farming movement in the developed countries.

THE URBAN-INDUSTRIAL IMPACT MODEL

In the conservation model, locational variations in agricultural development were related primarily to differences in enviromental factors. This stands in sharp contrast to models that interpret geographic differences in the level and rate of economic development primarily in in terms of the level and rate of urban-industrial development.

Initially, the urban-industrial impact model was formulated by von Thunen (in Germany) to explain geographic variations in the intensity of farming systems and in the productivity of labor in an industrializing society. In the United States, it was extended to explain the more effective performance of agriculture in regions characterized by rapid urban-industrial development, as opposed to regions where the urban economy had not made a transition to the industrial stage. In the 1950s, interest in the urban-industrial impact model reflected a concern with the failure of the agricultural resource development and price policies that were adopted in the 1930s to remove the persistent regional disparities in agricultural productivity and in rural incomes in American agriculture.

The rationale for the urban-industrial impact model was developed in terms of more effective input and output markets in areas of rapid urban-industrial development. Industrial development stimulated agricultural development by expanding the demand for farm products; by supplying the industrial inputs needed to improve agricultural productivity; and by drawing away surplus labor from agriculture. The empirical tests of the urban-industrial impact model have repeatedly confirmed that a strong non-farm labor market is an essential prerequisite for growth of labor productivity in agriculture and improvement in the incomes of rural people.

THE DIFFUSION MODEL

The diffusion of better husbandry practices was a major source of productivity growth even in pre-modern societies. The diffusion of crops and animals from the new world to the old -- potatoes, maize, cassava, rubber -- and from the old world to the new -- sugar, wheat, and domestic livestock -- was an important by-product of the voyages of discovery and trade from the 15th to the 19th centuries.

In the United States, the diffusion model has provided the major intellectual foundation of much of the research and extension effort in farm management, in rural sociology and economics since the emergence of these fields in the latter years of the 19th century. Experiment station research was not yet capable of making major contributions to agricultural productivity growth. Emphasis was placed on transferring knowledge and technology from leading farmers to lagging farmers and from progressive areas to backward areas. A further contribution to the effective diffusion of known technology was provided by the research of rural sociologists on the diffusion process.

The insights into the dynamics of the diffusion process, when coupled with the observation of wide agricultural productivity gaps among developed and less developed countries, and a presumption of inefficient resource allocation among "irrational tradition-bound" peasants, produced an extension or a diffusion bias in the choice of agricultural development strategy in many less developed countries during the 1950s. During the 1960s, the limitations of the diffusion model as a foundation for the design of agricultural development policies became increasingly apparent as technical assistance and rural development programs, based explicitly or implicitly on the diffusion model, failed to generate either rapid modernization of traditional farms and communities or rapid growth in agricultural output.

THE HIGH-PAYOFF INPUT MODEL

The inadequacy of policies based on the conservation, urban-industrial impact, and diffusion models led, in the 1960s, to a new perspective -- namely, that the key to transforming a traditional agricultural sector into a productive source of economic growth is investment designed to make modern high-payoff inputs available to farmers in poor countries. Peasants, in traditional agricultural systems, were viewed as rational, efficient resource allocators. This iconoclastic view was argued most vigorously by T. W. Schultz (1964). He insisted that peasants in traditional societies remained poor because, in most poor countries, there were only limited technical and economic opportunities to which they could respond. The new, high-payoff inputs were classified into three categories: (a) the capacity of public and private-sector research institutions to produce new technical knowledge; (b) the capacity of the industrial sector to develop, produce, and market new technical inputs; and (c) the capacity of farmers to acquire new knowledge and use new inputs effectively.

The enthusiasm with which the high-payoff input model has been accepted and translated into economic doctrine has been due, in part, to the proliferation of studies reporting high rates of return in the United States to public investment in agricultural research and in the education of farm people. It was also due to the success of efforts to develop new high-productivity grain varieties suitable for the tropics. New high-yielding wheat varieties were developed in Mexico, beginning in the 1950s, and new high-yielding rice varieties were developed in the Philippines in the 1960s. These varieties were highly responsive to industrial inputs, such as fertilizer and other chemicals, and to more effective soil and water management. The high returns associated with the adoption of the new varieties and the associated technical inputs and management practices have led to rapid diffusion of the new varieties among farmers in a number of countries in Asia, Africa, and Latin America (Figure 1).

AN INDUCED INNOVATION MODEL

The high-payoff input model remains incomplete as a theory of agricultural development. Typically, education and research are public goods not traded through the marketplace. The mechanism by which resources are allocated among education, research, and other public and private sector economic activities was not fully incorporated into the model. It does

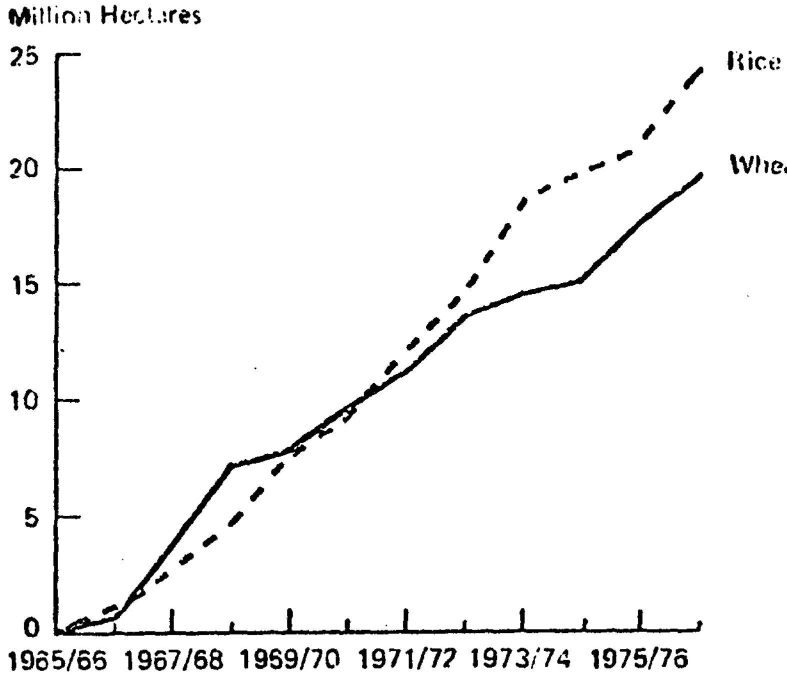

Figure 1. Estimated Area Planted to High-yielding Varieties of Wheat (Bangladesh, India, Nepal, Pakistan) and Rice (Bangladesh, Burma, India, Indonesia, S. Korea, W. Malaysia, Nepal, Phillipines, Sri Lanka, Thailand) in Asia (Dalrymple, 1978).

not explain how economic conditions induce the development and adoption of an efficient set of technologies for a particular society. Nor does it attempt to specify the processes by which input and product price relationships induce investment in research in a direction consistent with a nation's particular resource endowments.

These limitations in the high-payoff input model led to efforts by Hayami and Ruttan (1971) to develop a model of agricultural development in which the appropriate path of technical change is determined by a nation's resource endowments. The induced innovation perspective was stimulated by historical evidence that agricultural technology is highly location-specific and that different countries had followed alternative paths of technical change in the process of agricultural development (Figure 2).

There is clear historical evidence that technology has been developed to facilitate the substitution of relatively abundant (hence cheap) factors for relatively scarce (hence expensive) factors of production. The constraints imposed on agricultural development by a relative scarcity of land have, in economies such as Japan and Taiwan, been offset by the development of high-yielding crop varieties designed to facilitate the substitution of fertilizer for land. The constraints imposed by a relative

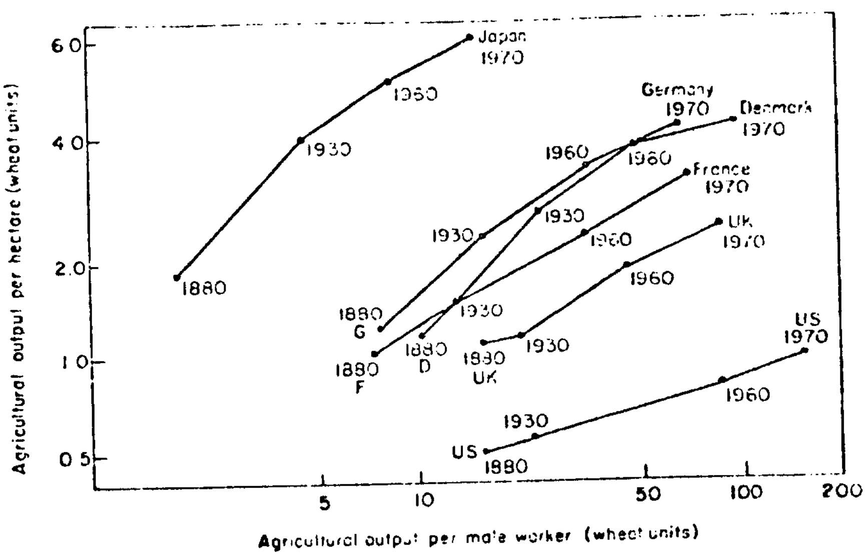

Figure 2. Historical Growth Paths of Agricultural Productivity in the U.S.A., Japan, Germany, Denmark, France and the UK, 1880-1970. Source: Vernon W. Ruttan, Hans P. Binswanger, Yujiro Hayami, William Wade and Adolf Weber, "Factor Productivity and Growth: A Historical Interpretation," in Binswanger and Ruttan, 1979.

scarcity of labor, in countries such as the United States, Canada, and Australia, have been offset by technical advances leading to the substitution of animal and mechanical power for labor. In some cases, the new technologies -- embodied in new crop varieties, new equipment, or new production practices -- may not always be substitutes for land or labor by themselves. Rather, they may serve as catalysts to facilitate the substitution of relatively abundant factors (such as fertilizer or mineral fuels) for relatively scarce factors.

In agriculture, mechanical technology can generally be described as "labor-saving" while biological (or biological and chemical) technology is "land-saving." The primary effect of the adoption of mechanical technology is not to increase yields. It is to facilitate the substitution of power and machinery for labor. Typically, this results in a decline in labor use per unit of land area. The substitution of animal or mechanical power for human labor enables each worker to extend his efforts over a larger land area.

The primary effect of adoption of biological technology is to facilitate the substitution of labor and/or industrial inputs for land. This may occur through increased recycling of soil fertility by more labor-intensive conservation systems; through the use of chemical fertilizers; and through husbandry practices, management systems, and inputs (i.e., insecticides) that permit a more favorable production response to human effort.

Historically, there has been a close association between advances in output per unit of land area and advances in biological technology; and between advances in output per worker and advances in mechanical technology. These historical differences have given rise to the cross-sectional differences in productivity and factor use illustrated in Figure 2.

INDUCED TECHNICAL INNOVATION IN THE UNITED STATES AND JAPAN

The working out of the theory of induced technical change in agriculture can be seen more clearly by drawing on the historical experience of the United States and Japan. In the United States, it was primarily the progress of mechanization, first using animals and later tractors for motive power, which facilitated the expansion of agricultural production and productivity by increasing the area operated per worker. In Japan, it was primarily the progress of biological technology such as higher yielding, more fertilizer-responsive crop varieties which permitted rapid growth in agricultural output in spite of severe constraints on the supply of land. These contrasting patterns of productivity growth and factor use in United States and Japanese agriculture can best be understood in terms of a process of dynamic adjustment to changing relative resource endowments and input prices.

In the United States, the long-term rise in wage rates relative to the prices of land and machinery encouraged the substitution of land and power for labor. This substitution generally involved progress in the application of mechanical technology to agricultural production. The more intensive application of mechanical technology depended on the invention of technology that was more extensive in its use of equipment and land relative to labor. For example, the Hussey or McCormick reapers in use in the 1860s and 1870s required, over a harvest period of about two weeks, five workers and four horses to harvest 140 acres of wheat. When the binder was introduced, it was possible for a farmer to harvest the same acreage of wheat with two workers and four horses. The process illustrated by the substitution of the binder for the reaper has been continuous. As the limits to horse mechanization were reached in the early part of the 20th century, the process was continued by the introduction of the tractor as the primary source of motive power. The process has been continued by the substitution of larger and higher-powered tractors and the development of self-propelled harvesting equipment.

In Japan, land was relatively scarce, and its price rose relative to wages. It was not, therefore, profitable to substitute power for labor. Instead, the new opportunities arising from the continuous decline in the price of fertilizer relative to the price of land were exploited through advances in biological technology. Crop variety improvement was directed, for example, toward the selection and breeding of more fertilizer-responsive varieties of rice. The enormous changes in fertilizer input per hectare that have occurred in Japan since 1880 reflect not only the effect of the response of farmers to lower fertilizer prices but the development by the Japanese agricultural research system of "fertilizer-consuming" rice varieties to take advantage of the decline in the real price of fertilizer.

The effect of relative prices in the development and choice of technology is illustrated with remarkable clarity in the case of fertilizer in Figure 3, in which United States and Japanese data on the relationship between fertilizer input per hectare of arable land and the fertilizer-land price ratio are plotted for the period 1880-1960. In both 1880 and 1960, U.S. farmers were using less fertilizer than Japanese farmers. However, despite enormous differences in both physical and institutional resources, the relationship between these variables has been almost identical in the two countries. As the price of fertilizer declined relative to other factors, both Japanese and American scientists responded by inventing crop varieties that were more responsive to fertilizer. However, American scientists always lagged by a few decades in the process because

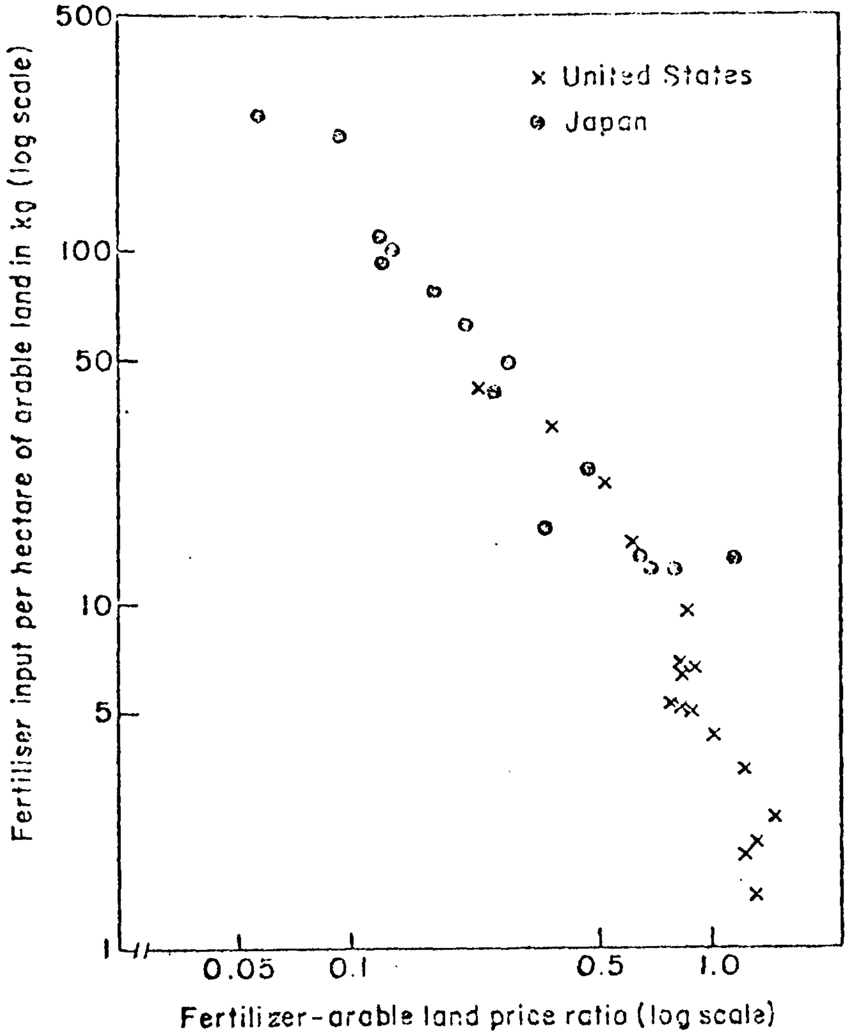

Figure 3. Relation Between Fertilizer Input per Hectare of Arable Land and the Fertilizer: Arable Land Price Ratio. Source: Hayami and Ruttan, 1971, p. 127.

the lower price of land relative to fertilizer resulted in a lower priority being placed on yield-increasing technology.

It is possible to illustrate the same process with cross-section data in the case of mechanical technology. Variations in the level of tractor horsepower per worker among countries are very largely a reflection of the price of labor relative to the price of power. As wage rates have risen in countries with small farms, such as Japan and Taiwan, it has been possible to adapt mechanical technology to the size of the farm.

The effect of a decline in the price of fertilizer relative to the price of land, or of the price of machinery and machinery services relative to the price of labor, has been to induce advances in biological and mechanical technology. The effect of the introduction of lower cost or more productive biological and mechanical technology has been to induce farmers to substitute fertilizer for land and mechanical power for labor. These responses to differences in resource endowments among countries and to changes in resource endowments over time by agricultural research institutions, by the farm supply industries and by farmers, have been remarkably similar in spite of differences in culture and tradition.

During the last two decades, as wage rates have risen rapidly in Japan and as land prices have risen in the United States, there has been a tendency for the pattern of technological change in the two countries to converge. During the decade of the 1960s, fertilizer consumption per hectare rose more rapidly in the United States than in Japan, and tractor horsepower per worker rose more rapidly in Japan than in the United States. Both countries appear to be converging toward the European pattern of technical change in which increases in output per worker and increases in output per hectare occur at approximately equal rates.

There will be further changes in the future. During the 1970s, the price of energy rose. This has affected both the price of fuel and the price of fertilizer. It is unlikely that declining energy prices will in the future serve as the focusing device that determines the direction of scientific and technical effort in advancing either mechanical or biological technology as during the past century.

THE CONTRIBUTION OF RESEARCH[2]

The beginning of successful modernization of agricultural production, as suggested in the previous section, is signaled by the emergence of sustained growth in productivity. During the initial stages of development, productivity growth is usually accounted for by improvement in a single partial productivity ratio such as output per unit of labor or output per unit of land. In the United States, and in other countries of recent settlement such as Canada, Australia, New Zealand, and Argentina, increases in labor productivity initially carried the burden of growth in total productivity. In countries that entered the development process with relatively high labor-land ratios, such as Japan, Taiwan, Denmark, and Germany, increases in land productivity were initially the primary source of productivity growth.

As modernization progressed, there has been a tendency for growth in total productivity -- output per unit of total input -- to be sustained by a more balanced combination of improvement in partial productivity ratios. Among the countries with the longest experience of agricultural growth, there tends to be a convergence in the patterns of productivity growth.

The changes in two partial productivity measures, land productivity

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[2]This section draws very heavily on material presented in Evenson, Waggoner and Ruttan (1979).

and labor productivity, and in total productivity are illustrated for U.S. agriculture for the period 1950-1978 in Figure 4. During the 1950s and early 1960s, all three productivity measures grew rapidly. During the late 1960s, the rate of growth of land productivity and total productivity slowed down. During the 1970s, these two productivity indexes appear to have renewed their upward trend. Note also that the labor productivity index grew more rapidly than the total productivity index throughout the entire period. Part of the growth in labor productivity is due to higher capital investment per worker. The total productivity index grew at a slower rate because the services of the capital equipment, along with labor and other inputs, are included in the input index.

In Tables 1 and 2, changes in total productivity and in the two partial productivity growth rates are presented for the United States and Japan for the period since 1870. The tables illustrate the point made earlier in this section. Prior to the mid-1950s, productivity growth in Japanese agriculture was dominated by growth in land productivity. Prior to the 1940s, productivity growth in U.S. agriculture was dominated by growth in labor productivity.

The tables also show that both countries experienced periods of relatively slow productivity growth. During the first quarter of the 20th century, the rate of growth in labor productivity declined in the United States. Total inputs grew more rapidly than output. Total productivity declined. Japan experienced its lowest rate of productivity growth during the period 1935-55.

Growth in total productivity has been influenced by a number of factors. Research leading to new knowledge and new technology has

Figure 4

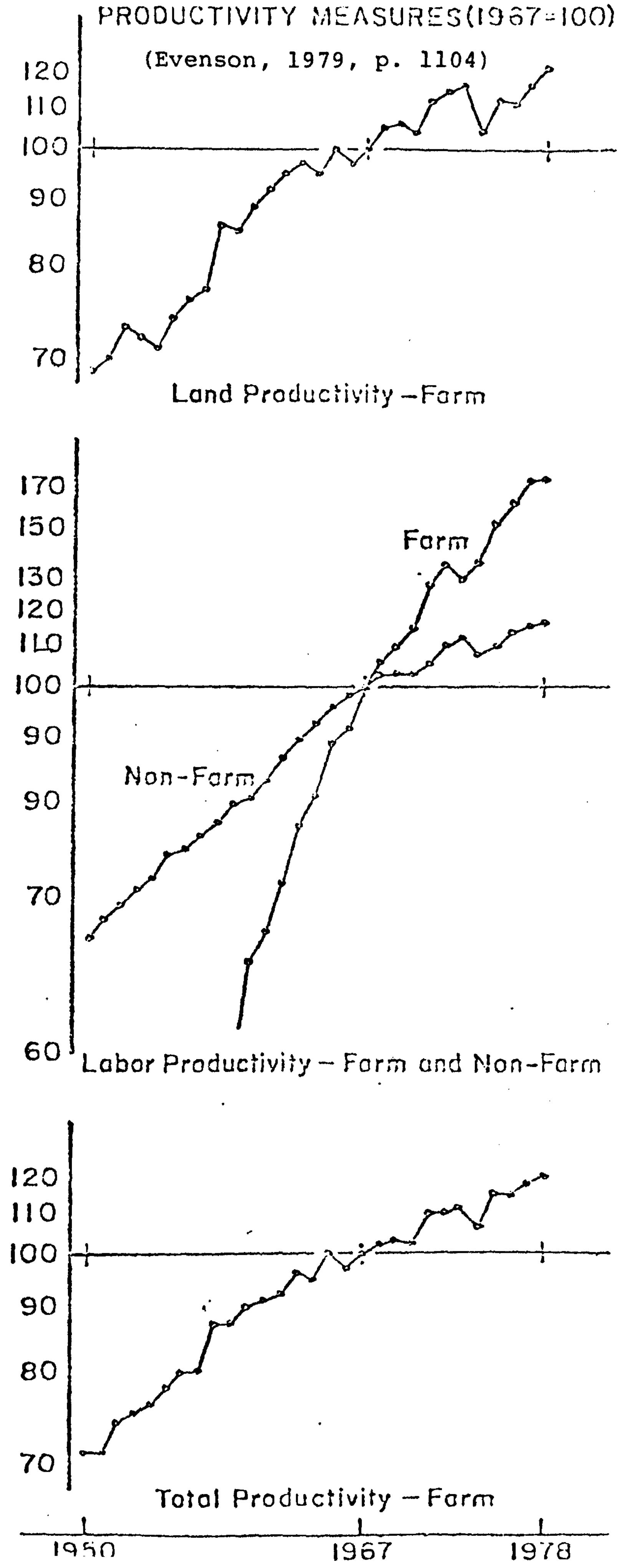
PRODUCTIVITY MEASURES(1967=100)
(Evenson, 1979, p. 1104)
120
110
100
90
80
70
Land Productivity – Farm
170
150
130
120
110
100
90
90
70
60
Farm
Non-Farm
Labor Productivity – Farm and Non-Farm
120
110
100
90
80
70
Total Productivity – Farm
1950
1967
1978

Table 1: Annual Average Rates of Change (Percent Per Year) in Total Outputs, Inputs, and Productivity in United States Agriculture, 1870-1979 (USDA, 1979).

ITEM	1870-1900	1900-1925	1925-1950	1950-1965	1965-1979
Farm output	2.9	0.9	1.6	1.7	2.1
Total inputs	1.9	1.1	0.2	-0.4	0.3
Total productivity	1.0	-0.2	1.3	2.2	1.8
Labor inputs[1]	1.6	0.5	-1.7	-4.8	-3.8
Labor productivity	1.3	0.4	3.3	6.6	6.0
Land inputs[2]	3.1	0.8	0.1	-0.9	0.9
Land productivity	-0.2	0.0	1.4	2.6	1.2

Table 2: Average Annual Change in Total Outputs, Inputs and Productivity in Japanese Agriculture, 1880-1975 (Yamada, 1979).

ITEM	1880-1920	1920-1935	1935-1955	1955-1965	1965-1975
Farm output	1.8	0.9	0.6	3.6	1.4
Total inputs	0.5	0.5	1.2	0.7	---
Total productivity	1.3	0.4	-0.6	2.9	---
Labor inputs	-0.3	-0.2	0.6	-3.0	-3.6
Labor productivity	2.1	1.1	0.0	6.6	5.0
Land inputs	0.6	0.1	-0.1	0.1	-0.7
Land productivity	1.2	0.8	0.7	3.5	2.1

clearly been important. The education of farm people through formal schooling, through organized extension activity, and through agricultural publications has contributed to the rapid diffusion and efficient use of new technology. Transportation improvements have reduced the costs of industrial inputs and the costs of marketing. Rural mail and telephone services have exerted a pervasive impact on productivity. The separate contributions of all of these factors have not yet been quantified. Considerable evidence has, however, been accumulated on the contribution of research and education.

The results of a large number of studies of the contribution of research to productivity growth have been assembled in Table 3. Almost all of the studies indicate rates of return to investment in agricultural research well above the 10-15 percent (above inflation) that is usually considered adequate to attract investment. It is hard to imagine many investments in either private or public sector activity that would produce more favorable rates of return.

The contributions of research to increased agricultural productivity have been studied primarily by two methods. The estimates listed under the "index number" heading were computed directly from the costs and benefits of research on, for example, hybrid corn. Benefits were estimated using accounting methods to measure the increase in production attributed to hybrid corn. The contribution of research was usually measured as the residual after all other factors that contributed to increased production were accounted for. The calculated returns represent the average rate of return per dollar invested over the period studied with the benefits of past research assumed to continue indefi-

Table 3: Summary studies of agricultural research productivity

Study	Country	Commodity	Time period	Annual internal rate of return %
Index number				
Griliches, 1958	USA	Hybrid corn	1940-55	35-40
Griliches, 1958	USA	Hybrid sorghum	1940-57	20
Peterson, 1967	USA	Poultry	1915-60	21-25
Evenson, 1969	South Africa	Sugarcane	1945-62	40
Ardito Barletta, 1970	Mexico	Wheat	1943-63	90
Ardito Barletta, 1970	Mexico	Maize	1943-63	35
Ayer, 1970	Brazil	Cotton	1924-67	77+
Schmitz & Seckler, 1970	USA	Tomato harvester	1958-69	
		with no compensation to displaced workers		37-46
		assuming compensation of displaced workers for 50% of earnings loss		16-28
Ayer & Schuh, 1972	Brazil	Cotton	1924-67	77-110
Hines, 1972	Peru	Maize	1954-67	35-40[a] 50-55[b]
Hayami & Akino, 1977	Japan	Rice	1915-50	25-27
Hayami & Akino, 1977	Japan	Rice	1930-61	73-75
Hertford, Ardila, Rocha & Trujillo, 1977	Colombia	Rice	1957-72	60-82
	Colombia	Soybeans	1960-71	79-96
	Colombia	Wheat	1953-73	11-12
	Colombia	Cotton	1953-72	none
Pee, 1977	Malaysia	Rubber	1932-73	24
Peterson & Fitzharris, 1977	USA	Aggregate	1937-42	50
			1947-52	51
			1957-62	49
			1957-72	34
Wennergren & Whitaker, 1977	Bolivia	Sheep	1966-75	44.1
		Wheat	1966-75	-47.5
Pray, 1978	Punjab (British India)	Agricultural research and extension	1906-56	34-44
	Punjab (Pakistan)	Agricultural research and extension	1948-63	23-37
Scobie & Posada, 1978	Bolivia	Rice	1957-64	79-96

Study	Country	Commodity	Time period	Annual internal rate of return %
Regression analysis				
Tang, 1963	Japan	Aggregate	1880-1938	35
Griliches, 1964	USA	Aggregate	1949-59	35-40
Latimer, 1964	USA	Aggregate	1949-59	not sig.
Peterson, 1967	USA	Poultry	1915-60	21
Evenson, 1968	USA	Aggregate	1949-59	47
Evenson, 1969	South Africa	Sugarcane	1945-58	40
Ardito Barletta, 1970	Mexico	Crops	1943-63	45-93
Duncan, 1972	Australia	Pasture improvement	1948-69	58-68
Evenson & Jha, 1973	India	Aggregate	1953-71	40
Cline, 1975	USA	Aggregate	1939-48	41-50[c]
(revised by Knutson and Tweeten, 1979)		Research and extension	1949-58	39-47[c]
			1959-68	32-39[c]
			1969-72	28-35[c]
Bredahl & Peterson 1976	USA	Cash grains	1969	
		Poultry	1969	
		Dairy	1969	
		Livestock	1969	
Kahlon, Bal, Saxena & Jha, 1977	India	Aggregate	1960-61-	63
Evenson & Flores, 1978	Asia--national	Rice	1950-65	32-39
			1966-75	73-78
	Asia--international	Rice	1966-75	74-102
Flores, Evenson 7 Hayami, 1978	Tropics	Rice	1966-75	46-71
	Philippines	Rice	1966-75	75
Nagy & Furtan, 1978	Canada	Rapeseed	1960-75	95-110
Davis, 1979	USA	Aggregate	1949-59	66-100
			1964-74	37
Evenson, 1979	USA	Aggregate	1868-1926	65
	USA	Technology oriented	1927-50	95
	USA	Science oriented	1927-50	110
		Science oriented	1948-1971	45
	USA - South	Technology oriented	1948-1971	130
	USA - North	Technology oriented	1948-71	93
	USA - West	Technology oriented	1948-71	95
	USA	Farm management research & Agricultural extension	1948-71	110

nitely. Benefits are defined as the benefits retained in the form of higher incomes to producers or passed on to consumers in the form of lower food prices.

The estimates listed under the "regression analysis" heading are computed by a different method, which permits estimation of the incremental return from increased investment rather than the average return from all investment. Further, this method can assign parts of the return to different sources, such as scientific research and extension advice. When regression methods are used, the significance of the estimated returns from research can be tested statistically. The dependent variable is the change in total productivity, and benefit is defined as the value of the change in productivity. The independent variables include research variables, which reflect the cost of research and the lag between investment and benefit. The objective of the regression procedure is to estimate that component of the change in productivity which can be attributed to research.

The effects of the timing and type of research have been analyzed in greater detail by Evenson (1978) for the United States.[3] These results, along with the regression equations used in the study, are presented in Table 4. Changes in the productivity of American agriculture from 1868 to 1971 were related to the research performed by

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[3]In the next several pages, I focus primarily on the results obtained by Evenson. A comparison with another important set of studies by researchers at Oklahoma State University and at the USDA is presented in appendix A. The Oklahoma State-USDA studies on research productivity include Cline (1975); Lu, Cline and Quance (1979); and Knutson and Tweeten (1979). A similar model has been employed in a study by White, Havlicek and Otto (1978).

Table 4: Estimated impacts of research and extension investments in U.S. agriculture

Period and subject	Annual rate of return %	Percent of productivity change realized in the state undertaking the research
1868-1926		
All agricultural research	65	not estimated
1927-1950		
Agricultural research		
Technology-oriented	95	55
Science-oriented	110	33
1948-1971		
Agricultural research		
Technology-oriented		
South	130	67
North	93	43
West	95	67
Science-Oriented	45	32
Farm management and agricultural extension	110	100

The Regression equations, standard errors of parameters (in parentheses), coefficients of determination (adjusted for degree of freedom), and numbers of observations (N) are as follows:

1868-1926

$$(1)\quad P = 45.29 + \underset{(.162)}{.521}\,INV + \underset{(.171)}{.813}\,RES + \underset{(23.38)}{3.04}\,LANDQ$$

$R^2 = .634$; N = 40 years

1927-1950

$$(2)\quad LN(P) = \underset{(.24)}{1.40}\,LN(INV) + \underset{(.037)}{.106}\,LN(TRES) + \underset{(.0000033)}{.0000053}\,LN(TRES)*(SRES)$$

$R^2 = .503$; N = 24 years x 4 regions

1948-1971

$$(3)\quad LN(P) = \underset{(.0085)}{.0331}\,LN(TRES\text{-}S) + \underset{(.0085)}{.0119}\,LN(TRES\text{-}N) + \underset{(.0089)}{.0187}\,LN(TRES\text{-}W)$$

+.2061 LN(TREX)* SRES + .3540 LN(ED) - .0394 LN (EXT)
(.0710) (.0426) (.0097)

-.0116 LN(EXT)*ED + .1821 LN(TRES)*EXT
(.0021) (.0230)

R^2 = .569; N = 23 years x 48 states

(4) LN(P) = .0299 LN(TRES-S) + .0040 LN(TRES-N) + .0113 LN(TRES-W)
(.0090) (.0090) (.0090)

+ .5639 LN(TRES)*SRES + .5855 LN(ED) - .02539 LN(EXT)
(.0104) (.0369) (.0102)

- .0196 LN(EXT)*ED + .1369 LN(TRES)*EXT + .00148 LN(TRES)* SUB
(.0021) (.0044) (.00017)

R^2 = .595; N = 23 years x 48 states

Each equation also included region and time period dummy variables. The 1948-71 equations also included a business cycle variable and a cross-sectional scaling variable.

Variables:

P; Total productivity index;
INV; Index of inventions;
RES Stock of all agricultural research with time weights;
LAND; Land quality;
TRES; Stock of technology oriented research with time and pervasiveness weights (S, W, N, for South, West North;
SRES; Stock of science oriented research;
ED; Schooling of farm operators;
EXT; Extension and farm management research stocks:
LN is natural logarithm;
*indicates variables multiplied.

the state agricultural experiment stations and the U.S. Department of Agriculture. The effects of agricultural extension and the schooling of farmers were also taken into account.

During the 1868-1926 period, an estimated 65 percent annual rate of return was realized on this investment. From 1927 to 1950, Evenson divided the research into two types. The first he called "technology-oriented," defined as research where new technology was the primary objective. This included plant breeding, agronomy, animal production, engineering, and farm management. The second type he called "science-oriented." Its primary objective was answering scientific questions related to the production of new technology. Science-oriented research included research in phytopathology, soil science, botany, zoology, genetics, and plant and animal physiology. The science-oriented research analyzed here is limited to that conducted in institutions such as the state experiment stations or the U.S. Department of Agriculture where it is closely associated with technology-oriented research. It is possible that the results might not apply, or would apply with a longer time lag, to science-oriented research isolated by organizational or disciplinary boundaries.

From 1927 to 1950, technology-oriented research yielded an annual rate of return of 95 percent. During the same 23 years, science-oriented research yielded an even high return, 110 percent. The 1927-50 period was one of substantial biological invention, exemplified by hybrid corn, improvements in the nutrition of plants and animals and advances in veterinary medicine. It was also a period of rapid mechanization. It is important to notice in the equations in Table 4 that science-oriented research (SRES) does not have a significant independent effect. The high payoff to science-oriented research is achieved only when it is directed toward increasing the productivity of technology-oriented research (TRES).

Research conducted in one state changes productivity in other states. This is referred to as "spillover." For 1927 to 1950 it was estimated that 55 percent of the change in productivity attributed to technology-oriented research conducted within a typical state was realized within that state. The remaining 45 percent was realized in other states with similar soils and climate. The spillover from science-oriented research was considerably greater. The observations of 1948 to 1971 for individual states allowed still more detailed analysis. Technological research continued to yield returns of over 90 percent. The payoff to research was especially high in the South, where research had lagged in earlier periods.

Science-oriented research from 1948 to 1971 remained profitable as it interacted with technological research, but it was less profitable than during 1927 to 1950. The decline in the rate of return to science-oriented research, both absolutely and relative to applied research, between 1927-50 and 1948-71, is difficult to interpret. One interpretation is that basic research has been a less serious constraint on advances in applied research in the more recent period than in the earlier period. A second interpretation is that there has been a lack of effective articulation between basic and applied research -- that either basic research has not been adequately focused in areas that are relevant to applied research or that applied research has not drawn adequately on potentially useful basic research. The continued high rates of return to applied research would seem to support the first interpretation.

Evidence concerning the effects on productivity of schooling and extension advice can also be obtained from the equations used to estimate the results presented in table 4. The schooling of farm operators had a strong positive effect. The effect of extension education and farm management advice is more complex. Its impact was strongest in those states with considerable technological research and farmers with little schooling. The effect of these interactions, combined with the direct effects of extension, was positive.[4]

The effect on productivity of locating research at multiple substations within each state was also captured by the regression equations of Table 4. There has been considerable debate on how a shift in the distribution of scientists between the central state stations and substations would affect the productivity of technological research. In the regression equation, the fraction in the substations (SUB) is multiplied by technological research (TRES). The interaction was positive and significant, indicating that decentralization has had a beneficial effect on the productivity of state research systems.

An important and somewhat unexpected inference from the several rates of return to agricultural research studies is that public-sector agricultural research has accounted for considerably less than half of the growth in agricultural productivity in recent decades. A 10 percent increase in public-sector expenditures for agricultural research appears

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[4]The contribution of extension to productivity growth has been analyzed in greater detail by Huffman (1978).

to increase the agricultural productivity index by only about 0.3 to 0.6 percent. This is only about one-fourth of the productivity growth rate in recent years.

But if rates of return to research are as high as suggested in table 3, why do ever larger increases in investment in agricultural research have so little leverage? The answer is found in a very substantial under-investment in agricultural research.[5] The total investment in agricultural research is so small relative to agricultural production that even investments with very high rates of return (at present levels of investment) have only a modest impact on the rate of growth of agricultural output and productivity.

Total public sector agricultural research expenditures are approximately $1.0 billion (Figure 5). Of this amount over 40 percent is from state appropriations. Estimates of agriculturally related research in the private sector also falls in the $1.0 billion range. However, about half of private sector research is conducted by or for the food industries and is not directed toward expanding agricultural production.

CAN PRODUCTIVITY GROWTH BE SUSTAINED?

Will investment in research be adequate to sustain output and productivity growth in American agriculture in the future? Before an attempt is made to respond to this question, it will be useful to review again the record of output and productivity growth during the last several decades (Table 1).

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[5]For an examination of some of the factors which explain the continued under-investment in agricultural research in the United States, see Evenson, Waggoner and Ruttan (1979) and Ruttan (1980).

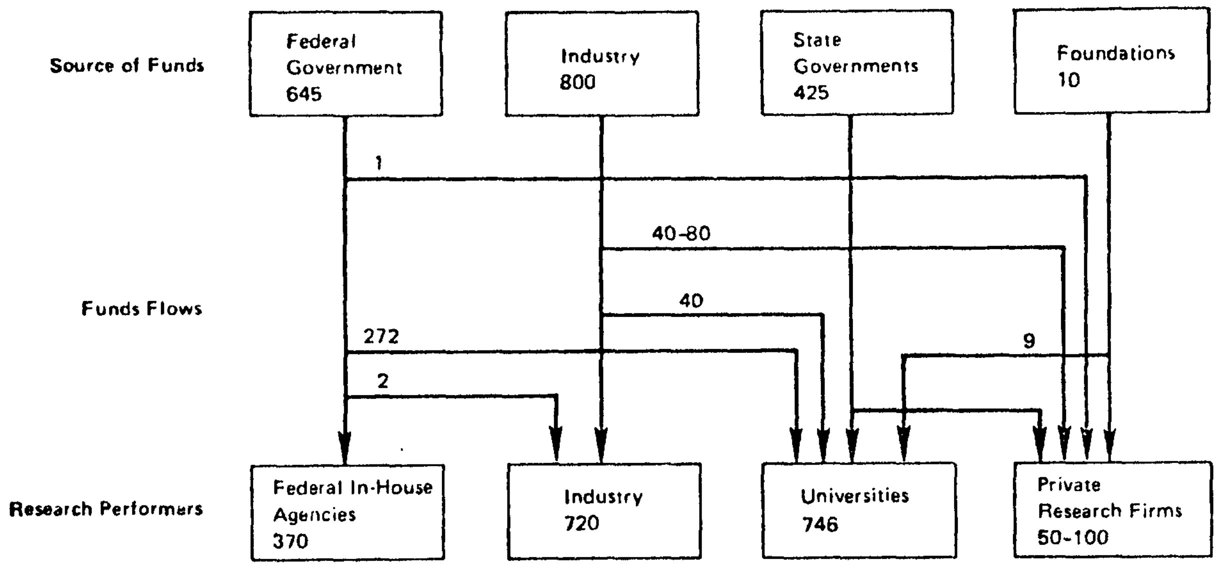


Figure 5. Research and development funds for the U.S. food research systems, 1976 ($ million). Source: Commission on International Relations, National Research Council, 1977, p. 22.

The rate of growth of agricultural output increased from an annual rate of 1.7 percent in 1950-65 to an annual rate of 2.2 percent during 1965-79. The 1965-79 rate was the highest for any sustained period since the turn of the century, and it was achieved in spite of a decline in the rate of productivity growth. The annual rate of total productivity growth declined from 2.2 percent in 1950-65 to 1.8 percent in 1965-79. The rate of increase in labor productivity declined from 6.6 percent to 6.0 percent and the rate of increase in land productivity declined from 2.6 percent to 1.2 percent. Rising real prices of agricultural commodities were able to draw additional resources into production and thus permit the rate of growth of output to rise in spite of a decline in the rate of productivity growth.

The evidence on lagging productivity growth has focused considerable concern on whether the support for agricultural research has been adequate to sustain future productivity growth. This concern has been reinforced by limited growth of federal support for agricultural research since the mid-1960s (Figure 6). Support for agricultural research expanded rapidly between 1950 and 1965. Between 1965 and 1978, federal support for agricultural research grew, in real terms, at 0.4 percent per year. However, non-federal support grew at an annual rate of 3.9 percent during this latter period.

This lag in the allocation of resources to research is in sharp contrast to the recommendations that had emerged out of the very intensive joint U.S. Department of Agriculture/State Experiment Station research planning effort in 1966. The projections presented in the National Program suggested the need for a 76 percent increase in scientific man-years between 1965 and 1977. It also recommended a modest shift in priorities from the commodity production, protection, and marketing categories toward the consumer protection and community development areas (Figure 7). During the projection period, there was a reallocation of scientific man-years among research program areas roughly in line with the National Program recommendations. However, total scientific man-years devoted to agricultural research increased by less than 5 percent--from approximately 10,500 to just under 11,000. This overall increase conceals an actual decline in the number of USDA scientists that was slightly more than offset by an increase in the number of scientists at the state experiment stations.

Figure 6
Purchasing Power of Federal Appropriations and Non-federal Support of Agricultural Research Programs in the U.S. for 1960-1978
(Liska, 1979)

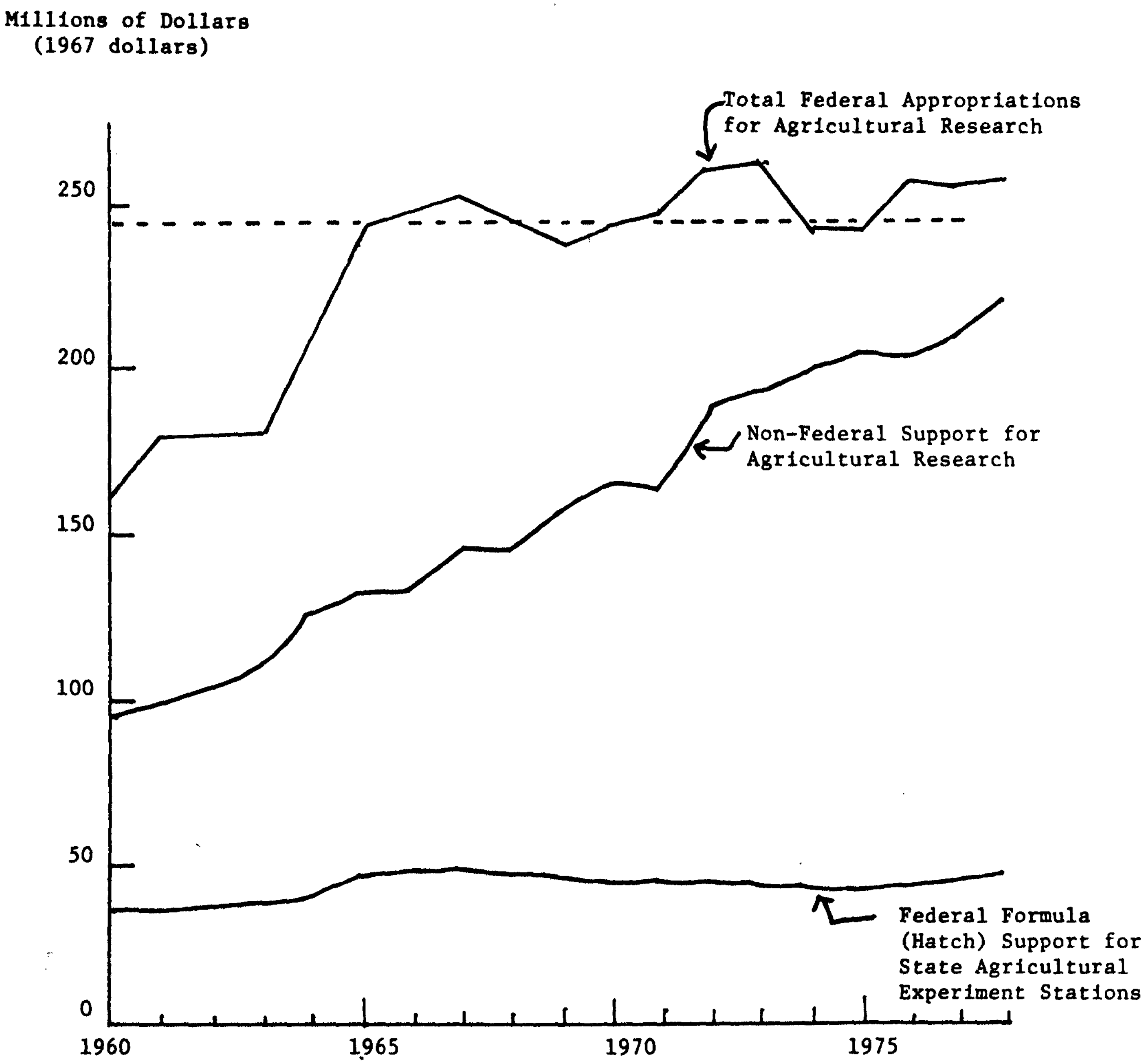
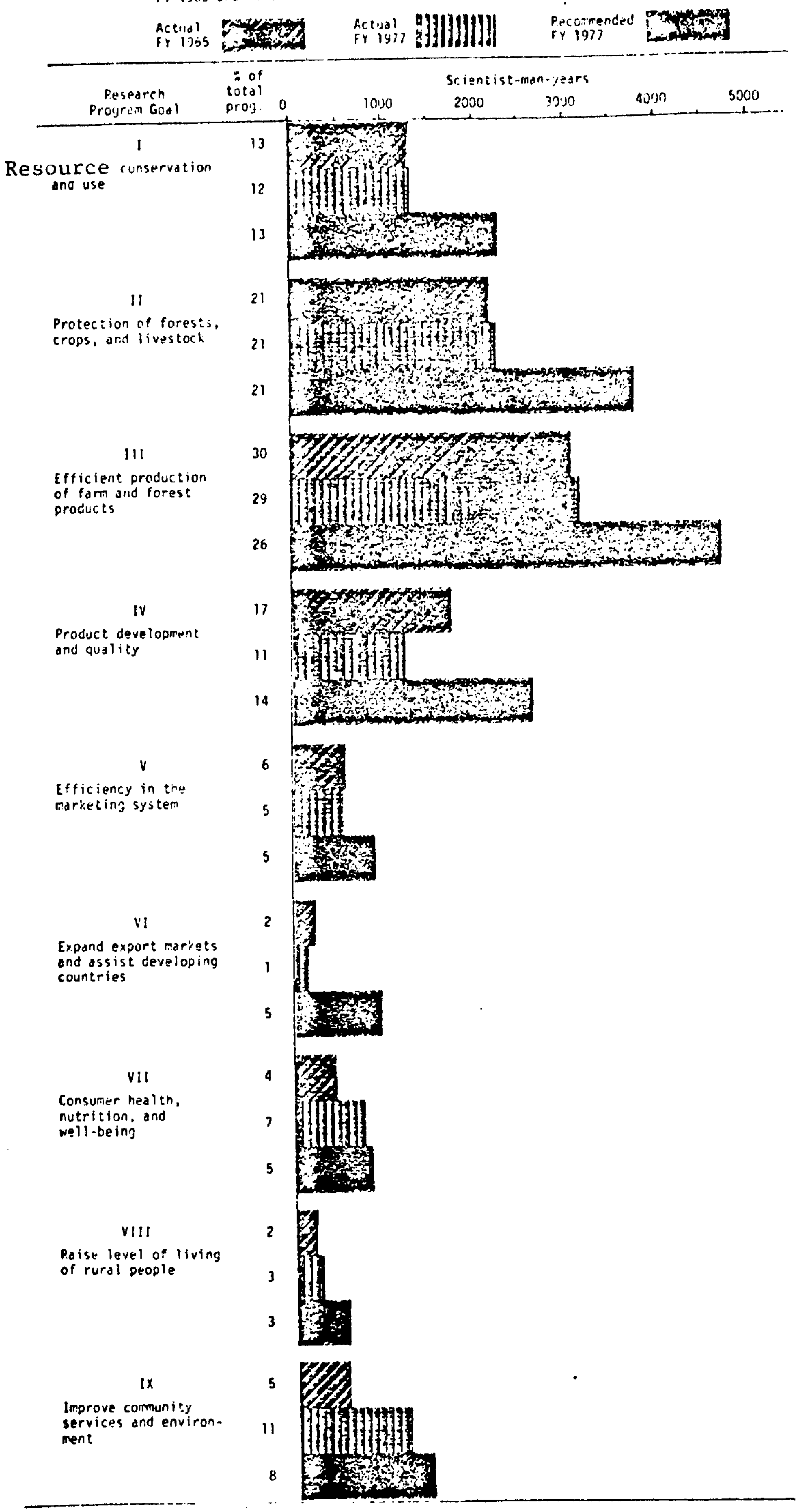


Fig. 7 Scientist-man-years in SAES-USDA Program by Research Goal for FY 1965 and FY 1977 Compared to Recommended for 1977



Source:
1965 actual and 1977 recommended: U.S. Department of Agriculture, A National Program of Research for Agriculture, Washington, D. C., October 1966.
1977 actual: U.S. Department of Agriculture, Inventory of Agricultural Research, FY 1977, Washington, D. C., USDA Science and Education Administration, March 1979.

The food crisis associated with the dramatic increase in grain imports by the USSR, the drought in the Sahel and in South Asia, and the sharp increased in petroleum prices in 1973-75 triggered a new set of evaluations of the adequacy of support for agricultural research (National Academy of Sciences, 1975a and b, Office of Technology Assessment, 1977). These studies had no more impact than the National Program in inducing an expansion in research support, but they did result in a number of changes in the organization, administration, and funding of agricultural research at the federal level. One of these changes that has attracted considerable attention is the initiation of the USDA competitive grants program (Bredahl, Bryant and Ruttan, 1976).

What conclusions can be drawn from the lag in research funding about the prospects to productivity growth in U.S. agriculture? Direct efforts to use historical research productivity estimates to project the effect of the future level of research support on productivity growth and on agricultural production capacity have been made by Lu, Cline, and Quance at the USDA (1979) (Table A1-2) and by Knutson and Tweeten (1979) at Oklahoma State University (Table A1-3).

The USDA study projections, based on the historical model estimated by Cline for 1929-1972, were used to stimulate several scenarios for 1974-76 to 2000 and 2025. These results indicate:

> 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 in total productivity is 1 percent. Under a baseline scenario in which 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 new technologies, productivity can be expected to maintain the 1.5 percent historical growth rate of the past 50 years. (p. 31)

The unprecedented new technologies that are built into the high technology scenario are photosynthesis enhancement, bioregulators, and induced twinning (in beef cattle). Their effect is to reduce the cost of achieving productivity growth. It is assumed that these new technologies will begin to have an impact on crop and animal production in the 1990s, but that their major impact would be delayed until after 2000.

The projections developed by Knutson and Tweeten are also built on the model developed by Cline. They developed three somewhat different scenarios. The first is a constant 3 percent per year real increase from 1976 to 2015; the second, a 10 percent annual increase from 1976-80 to catch up with the lag in research funding between 1966-76, followed by a 3 percent annual increase from 1981 to 2015; the third incorporates a 10 percent increase from 1976-80, followed by a 7 percent annual increase for 1981-2015 (table A1-3). These projections suggest considerable difficulty in maintaining a productivity growth rate of 1 percent per year even after a significant "catch up" boost in research expenditures.

No attempt has been made to derive explicit projections based on Evenson's work. However, his results suggest somewhat greater leverage of research expenditures on productivity than implied by the Oklahoma-USDA estimates.

In interpreting projections based on either the Oklahoma-USDA or inferences about future productivity growth based on the Evenson analysis, several major qualifications should be observed. It was noted earlier that public-sector research accounted for only about one-fourth of productivity growth in the agricultural sector during 1950-1979. In both models, the increase in the educational level of farm people contributed even more importantly than research to productivity growth. My own guess is that improvements in the education of farm people will become a less important source of U.S. productivity growth in the future than in the past. A source of growth that is inadequately captured in both models has been the structural transformation of American agriculture--measured, but not fully captured, by the shift of labor out of agriculture and the growth in farm size. My own guess is that structural change will also be a less powerful source of productivity growth in the future than in the past.

Another factor is not adequately captured is the effects on productivity growth of private sector R & D and extension-type activities. Firm information on the expenditures and productivity for private sector R & D are difficult to come by. Estimates presented by the World Food and Nutrition Study (1977) and by the Agricultural Research Council (Williamson and Wilcke, 1977) suggest that expenditures on agricultural research and development in the private sector are roughly equal to expenditures by the public sector (Figure 6). Private-sector agricultural research is much more heavily weighted toward the development end of the R & D spectrum, and in some areas, such as research on pesticides and animal drugs, defensive research designed to secure or protect product registration has risen sharply during the last decade. In addition to the organized R & D efforts in the machinery, chemicals, and seed companies, the less formal developmental efforts by farmers, mechanics, and the smaller machinery firms that do not get reported as research and development expenditures continue to be an important source of advances in mechanical technology. My guess is that private sector R & D will become a larger source of productivity growth in agriculture during the next several decades. There is need for much more careful analysis of the organization and productivity of private sector R & D and of its articulation with public sector R & D. The Office of Technology Assessment (OTA) is currently engaged in a review of the USDA proposals for reduction in public-sector involvement in research and development on post-harvest technology and marketing. The USDA has taken the position that the reduction in public-sector research and development in these areas will be assumed by the private sector.

What implications can be drawn from the formal analysis and intuitive insights that are available to us to assess future rates of productivity growth? I find it hard to escape a conclusion that, unless the political and economic climate changes significantly, public-sector agricultural research expenditures in the United States in the immediate future will expand at considerably less than the annual real rate of 3 percent per year employed in the Oklahoma-USDA projections. Even when we attempt to account for the unaccounted, it is difficult to avoid a conclusion that the lag in research funding during the 1965-80 period will be followed by further declines in total productivity growth during the 1980-2000 period.

I am skeptical, however, that we can expect to see a decline to 1 percent per year for a sustained period. At the same time, even a substantial effort to cash in on the higher rates of return available for agricultural research through rapid growth of research support will have great difficulty pushing the rate of productivity growth much above 1.5 percent per year. Even this would result in a continued decline from the 2.2 percent per year achieved during 1950-65 and the 1.8 percent achieved in 1965-79. This suggests a productivity growth rate more in line with the 1925-50 experience than with the 1950-80 experience. It also suggests that prices of agricultural commodities will have to rise relative to the price of purchased inputs if output is to grow in the 1.5 to 1.6 percent annual range suggested in recent demand projections (White, Havlicek and Otto, 1978). Considerable caution is warranted, however, because of our limited capacity to project productivity growth rates over even the relatively short span of 20 years (see Appendix 2, which describes how far some past projections came from anticipating actual productivity change).

A PERSPECTIVE

I would now like to return to the implications of the induced innovation model outlined earlier in this paper. In retrospect, it appears that the major error in the resource and technology assessment studies of the early 1950s (Appendix 2) was a failure to understand the implications of declining real energy prices, particularly energy embodied in chemical inputs, as a focusing device for directing scientific and technical effort. As a result, the effects of the substantial interaction between advances in chemical and biological technology were underestimated.

There is now something approaching a consensus that the real price of energy embodied in agricultural inputs will rise in the future.

Even those who resist this perspective do not expect real energy prices to decline over the next several decades. What will be the direction of technical effort induced by the changing input-input and input-product price relationships? My reading of the literature and sampling of scientific opinion suggest that we do not know. The closest analogy to the present situation in American agricultural history was the period between 1900 and 1925 (Table 1). With the closing of the frontier, productivity growth declined. The new sources of productivity growth, chemical and biological technology, did not begin to emerge for several decades. My guess is that it will be at least another decade before the direction of technical change induced by the rising real price of energy becomes clear.

The above perspective, if correct, has important implications for agricultural research management. Since we do not know where we are going, it is important that the exploration for new routes be kept as open as possible. Under these conditions, centralization of research management, particularly attempts to achieve a high degree of coordination among states and between the state and federal system, may come at a high price. This is a time to encourage parallel research and development efforts.[6] As the uncertainty increases, the value of redundancy rises. The historical evidence on research productivity suggests that a decentralized system more than compensates in productivity for the apparent losses due to redundancy. It is a time to avoid premature consensus on the opportunities that are ahead of us.

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[6]For arguments which suggest the gains from parallel research and development efforts, see Nelson (1961) and Herschman and Lindbloom (1962).

This places an extraordinary burden on research administrators in the states and in the USDA. They must go to the state legislatures and the U.S. Congress with requests for expanded research resources. Yet there is no way that they can be confident where the highest payoff to the research resources that become available to them will be found. These judgments can only be made with any degree of authority by scientists who are on the leading edge of the individual disciplines and problem areas.

The evidence presented here also imposes a severe burden on the legislative bodies that provide the funding for public sector agricultural research. The gains from agricultural research are realized with considerable time lag and over an extended period. This also means that the cost of current failure to fund agricultural research adequately, whether measured in terms of output and productivity growth, costs of production, food prices, or export earnings, will be felt only after considerable delay. Legislative bodies, like the rest of us, find it easier to deal with trade-offs between immediate short-run costs and benefits than between current costs and future benefits.

Appendix 1. The Oklahoma State-USDA Research Productivity Studies

The internal rates of return reported by Evenson are substantially higher than the rates reported in another series of important studies conducted at Oklahoma State University and at the U.S. Department of Agriculture by Cline (1975), Lu, Cline, and Quance (1979) and by Knutson and Tweeten (1979). Some results from the Oklahoma State-USDA studies are summarized in Table A1-1.

At least part of the difference between the Evenson and the Oklahoma State-USDA estimates may be due to several of the differences in specification. The Evenson specification is more complete. In the Oklahoma-USDA study, a single rate of return is estimated for the combined effect of both research and extension. The Evenson results permit a separation of the effects of research and extension on productivity.

The Evenson results also employ a revision of the USDA productivity index, constructed by shifting factor weights annually (an approximation to the Divisa Index) rather than the periodic base period shift (the Laspeyres Index) employed by the USDA. As a result of this adjustment, the index constructed by Evenson rose more rapidly than the USDA index during the late 1960s. The effect of this revision is to increase the research coefficients in the Evenson estimates.

The coefficient for education (E) is higher in the Oklahoma-USDA specification than in the Evenson specification. This may be due, in part, to the inclusion of farm workers as well as farm operators in the Oklahoma-USDA specification. But it also seems likely that the Oklahoma-USDA estimates are picking up some of the effects of other omitted variables.

Table A1-1: Marginal Internal Rates of Return (%) to Production-Oriented Research and Extension during Specified Time Periods (Knutson, 1979)

Period	13-Year-Lag	16-Year Lag
1939-48	40.9	49.7
1949-58	38.8	47.4
1959-68	31.6	39.4
1969-72	28.0	35.5

The regression equations employed in estimating the above internal rates of return was:

$$\ln P_t = \sum_{i=0}^{n} \beta_i \ln R_{t-1} + \beta_{n+1} \ln O_t + \beta_{n+2} \ln E_t + \beta_{n+3} \ln W_t + U_i$$

where

R_{t-1} = public sector production oriented research and extension in preceding periods

O_t = public sector non-production oriented research and extension in the present period

E_t = educational attainment, farmers and farm laborers in current period

W_t = weather index for the current period

The results for the 13 and 16 year lag relatively were as follows

	$\ln R_{t-1}$ ($\sum_{t=0}^{n} \beta_i$)	$\ln E_t$	$\ln W_t$	R_2	SEE[c]	DW[d]	$\hat{P}$[e]
(1) 13 year:	.0369[a]	.7851	.0020	.999	.02036	2.29	.839
		(3.0440)[b]	(4.7337)				
(2) 16 year:	.0595[a]	.7299	.0020	.999	.02116	2.20	.819
		(2.5554)	(4.3906)				

Table A1-1 continued

[a]A joint F test for each equation of the null hypothesis that all the regression coefficients for R's are equal to zero was rejected at the 1% level of significance in each case.

[b]Numbers in parentheses are t-values.

[c]Standard error of the estimate.

[d]Durbin-Watson "d" statistic.

[e]The estimated value of the first-order autoregression coefficient of the disturbances.

Table A1-2: Annual Compound Rate of Growth in Agricultural Productivity Under Alternative Rates of Investment in Research and Extension and Growth of Education of Farmers and Farm Workers, 1980-2000. (Lu, 1979)

	No Growth in R & E	Slow Growth in R & E	Rapid Growth in R & E	Rapid Growth in R and E plus unprecedented new technologies
Education	1.2	1.2	1.2	1.2
Research and Extension	0.0	3.0	7.0	7.0
Productivity	1.0	1.1	1.2	1.3

Table A1-3: Annual Compound Rate of Growth (%) in U.S. Agricultural Productivity (Output per Unit of Conventional Inputs) under Various Scenarios by Selected Time Periods, 1976-2015
(Knutson, 1979, p. 72)

Period	Scenario		
	T_3	$T_{10/3}$	$T_{10/7}$
1976-1985	1.036	1.102	1.115
1986-1995	.954	1.032	1.173
1996-2005	.866	.866	1.072
2006-2015	.801	.801	.986

Note: Productivity growth was estimated with lag length of 16 years (see table 6).

The increases in research expenditures projected in the three scenarios are as follows:

T_3 = a constant 3% annual increase from 1976 to 2015

$T_{10/3}$ = a 10% annual increase from 1976-80 followed by a 3% annual increase from 1981-2015.

$T_{10/7}$ = a 10% annual increase from 1976-80 followed by a 7% annual increase from 1981-2015

Appendix 2. A Retrospective View of Alternative Output, Input and Productivity Projections, 1950-75

It may be useful to illustrate my caution about our capacity to project productivity growth rates by comparing a set of output/input and productivity growth rate projections for 1960 and 1975 that I made in the mid-1950s, with changes that have occurred over the projection periods (Table A2-1). The projections were made to evaluate the implications of the projections of resource investment requirements being made by the U.S. Department of Agriculture, the President's Water Policy Commission Report, and the President's Materials Policy Commission Report. These reports were concerned with the capacity of American agriculture to meet future food and fiber requirements. The emphasis of the several studies was on "the transitory nature of present food surpluses." Both reports projected substantial increases in land resource inputs to meet output requirements.

The approach employed in assessing these projections was to use an equation of the Cobb-Douglas type (linear in the logarithms), with a shift factor that captured the effect of productivity growth, to examine the consistency between the projected output requirements and alternative rates of growth of inputs and productivity. Four basic models with annual rates of productivity growth ranging from zero to 2.4 percent per year were calculated. The projections implied that continuation of even the relatively slow historical productivity growth rates could permit a relatively rapid growth in output with modest changes in land inputs (plus or minus 10 percent). The realized rate of productivity growth was, however, much higher than anticipated.

It approached the most rapid rate projected. The other input projections were even less accurate. The decline in labor input was substantially underestimated in all models. And the current input levels that were actually realized were almost as high as those projected in the zero technical change model.

The projections in Table A2-1 were, of course, made at a time when the quantitative relationship between research investment and productivity growth were not as well understood as at present. Productivity accounting was a new craft. The Griliches study of the rate of return to investment in hybrid corn research (Table 3) was several years in the future. Nevertheless, my cautious pessimism of the present may be only slightly more firmly grounded than my cautious optimism of the mid-1950s.

Table A2-1: Alternative Projections and Realized Farm Output and Factor Input Indexes for 1960 and 1975 (1950 = 100)
(Projections: Ruttan, 1956; Realized: USDA, 1978)

	Zero technical progress[a]		Slow technical progress[b]		Rapid technical progress[c]		Very rapid technical progress[d]		Realized technical progress[f]
	Low land inputs (I)	High land inputs (II)	Low land inputs (III)	High land inputs (IV)	Low land inputs (V)	High land inputs (VI)	Low land inputs (VII)	High land inputs (VIII)	
1960 Projections									
Inputs:									
Labor	88	88	88	88	78	78	78	78	65
Land	96	104	96	104	96	104	96	104	90
Capital[c] (A)	178	172	140	136	149	143	124	121 }	114
(B)	183	177	145	140	153	147	127	124	
Current[e] (A)	214	207	169	163	178	172	148	145 }	170
(B)	204	198	161	155	171	164	141	138	
Contribution to output from:									
Inputs	122	122	112	112	110	110	100	100	96
Technological change	0	0	10	10	12	12	22	22	24
Total output	122	122	122	122	122	122	122	122	118
1975 Projections									
Inputs:									
Labor	81	81	81	81	67	67	67	67	30
Land	90	110	90	110	90	110	90	110	96
Capital[e] (A)	346	318	199	169	218	201	132	122 }	133
(B)	378	348	218	185	238	219	144	133	
Current[e] (A)	547	505	317	240	346	318	210	193 }	472
(B)	491	441	285	234	311	277	189	173	
Contributions to output from:									
Inputs	160	160	135	135	129	129	100	100	96
Technological change	0	0	25	25	31	31	60	60	54
Total output	160	160	160	160	160	160	160	160	150

Footnotes for Table A2-1

[a] Increased inputs are assumed to account for the entire increase in output.

[b] Technological change is assumed to occur at a sufficiently rapid rate to permit an increase in output per unit of input of 1.0 percent per year between 1950 and 1975. This is the 1910-50 rate calculated on the basis of 1945-48 prices and techniques.

[c] Technological change is assumed to occur at a sufficiently rapid rate to permit an increase in output per unit of input of 1.23 percent per year between 1950 and 1975. This is the 1910-50 rate calculated on the basis of 1910-14 prices and techniques.

[d] It is assumed that technological change occurs at a sufficiently rapid rate to account for the entire increase in output. This requires an increase in output per unit of input of 2.2 percent per year between 1950 and 1960 and 2.4 percent per year between 1950 and 1975.

[e] Estimate (A) for capital and current inputs is based on the assumption that the ratio of capital to current inputs (C_1/C_2) will continue to decline at the same percentage rate as during the period 1910-14 to 1945-48. Estimate (B) is based on the assumption that the 1925-27 to 1949-50 rate will continue. See text for further discussion of estimates A and B.

[f] **Calculated for 1948-53, 1958-63 and 1973-77. Capital indexes based on mechanical power and machinery; current inputs based on agricultural chemicals.**

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