Chapter IV

Measuring Costs, Benefits, Burdens, and Quality of Research

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Measuring Costs, Benefits, Burdens, and Quality of Research

Achievements in agricultural research and technology have contributed markedly to the economic stature and social well-being of the United States and have enhanced our standing among world powers in many ways. Such achievements, however, have not been attained without certain costs and burdens to society. In other words, the benefits accruing from research must be weighed against the magnitude of whatever dollar and manpower investments are required, together with such factors as impact on environmental quality, labor displacement, or impairment of sensory quality caused by mass food production, Most evaluations show, however, that the benefits far outweigh the costs and burdens. Actually, on a rate-of-return basis, consumers reap benefits well in excess of costs.

Among scientists themselves, attempts have been made at various times to measure the quality of research performance but it is also important to measure research productivity and its ultimate impact on society as a whole, Although trends in funding U.S. food and agricultural research show only modest increases over time, the cumulative benefits to all segments of society would seem to more than justify whatever investments have been made.

TRENDS IN FUNDING

Food and agricultural research in the United States is conducted chiefly by the U.S. Department of Agriculture (USDA); the State agricultural experiment stations (SAES) in conjunction with land-grant universities, including the 1890 Schools and Tuskegee Institute; and private industry. USDA and SAES research constitute public research regardless of the source of supporting funds. USDA agricultural research is funded from Federal sources. SAES research is supported by Federal funds, State appropriations and sales, and grants from private sources.

The scope and magnitude of food and agricultural research performed by private industry cannot be accurately reported because of the lack of reliable data. Private firms engaged in agricultural research are not required to identify themselves, nor are they required to publicly disclose their investments in agricultural research. Thus, any analysis of agricultural research by private industry has to be based on incomplete data. Those figures that are available will be discussed later in this chapter.

Accurate figures are available for total expenditures on food and agricultural research by USDA and the SAES. In this segment of the report, patterns and trends in expenditures focus on the period 1966 to 1979. Note that figures are given for expenditures in current dollars and constant dollars—that is, dollar expenditures adjusted for inflation. The deflator factor used for this study is explained by Havlicek and Otto in their OTA resource paper.

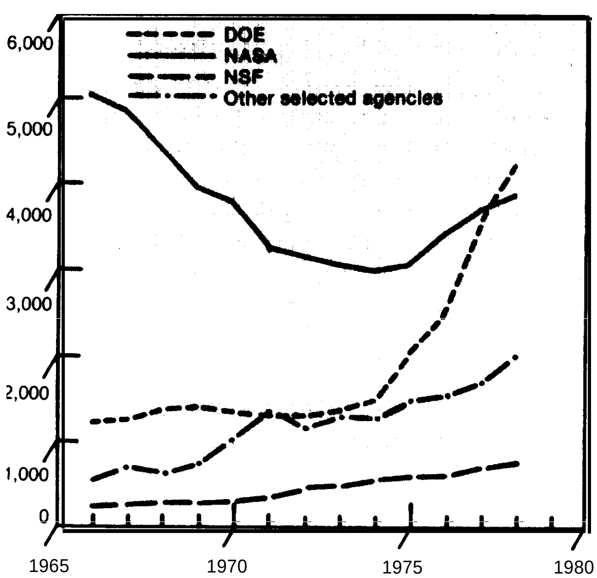
R&D Expenditures by Federal Agencies

Among the major Federal research agencies that conduct research and development (R&D), USDA expenditures are the lowest in terms of dollar expenditures. In 1978, total Federal expenditures for R&D were $26.2 billion. USDA's expenditures were $381 million or approximately 1.5 percent of the total. This compared with Department of Defense (DOD) share of 45 percent; Department of Energy (DOE) of 16 percent; and Department of Health, Education, and Welfare (HEW) of 12 percent. USDA's status among Federal agencies represents a continuing decline in share of the Federal budget for R&D from a high of 39 percent in 1940 to 1.5 percent in 1978.

Federal obligations for all R&D by the National Aeronautics and Space Administration (NASA), the National Science Foundation (NSF), DOE, and a category of other selected agencies for the 1966-78 period (the most recent available data) are presented in current dollars in figure 8 and constant dollars in figure 9. The level of funding for NASA is large relative to the other agencies considered. As may be observed from figures 8 and 9, R&D funding for NASA decreased from 1966 to 1974 and thereafter increased, although in constant dollars the increase from 1974 to 1978 was quite small. R&D funding for DOE increased in current dollars from 1972 to 1978, but in constant dollars did not increase until after 1974. In current and constant dollars, R&D funding for NSF increased steadily during the 13-year period. R&D funding for "all other agencies" increased about 270 percent in current dollars during the 1966-78 period, but in constant dollars increased about 67 percent.

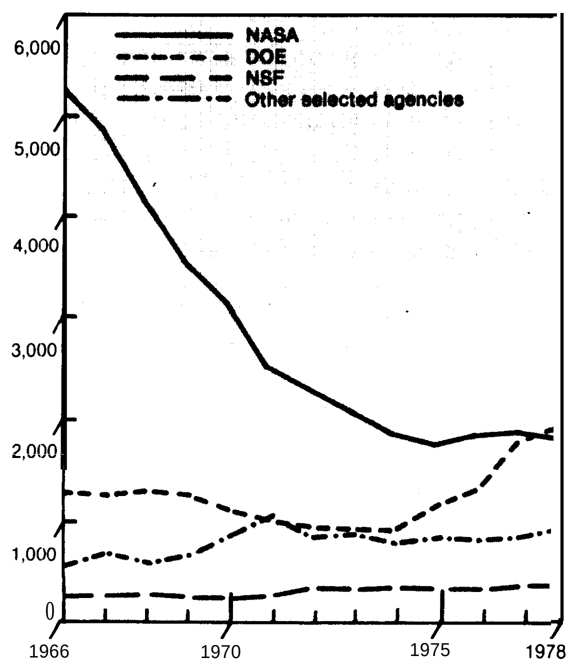
R&D expenditures for USDA, DOD, HEW, and the total for all Federal agencies for the 1966-78 period are presented in current dollars in figure 10 and in constant dollars in figure 11. In current dollars, R&D expenditures by DOD increased 68 percent from 1966 to '1978, but in constant dollars this represented a decline of 26 percent; R&D funding for HEW increased steadily by 209 percent from 1966 to 1978, and in constant dollars the expenditures increased 35 percent. In current dollars, R&D funding for USDA, which in-

Figure 8.–Federal Obligations for R&D by NASA, DOE, NSF, and Other Selected Agencies—1966.78 (in millions of current dollars)



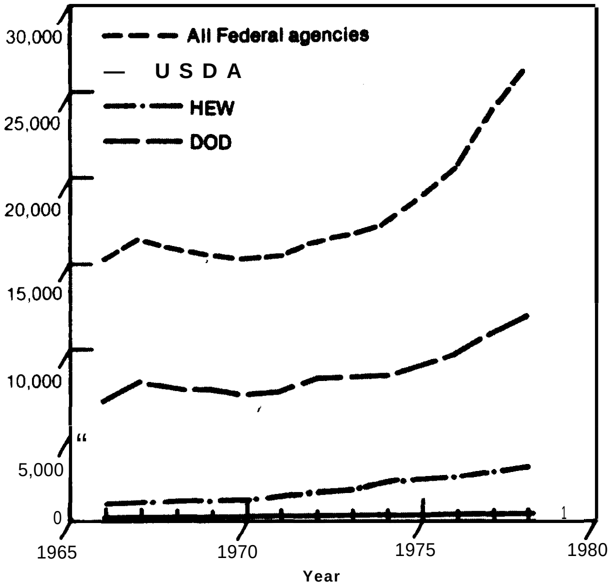
SOURCE: Joseph Havlicek, Jr , and Daniel Otto, "Historical Analysis of Investment in Food and Agricultural Research in the United States, " OTA background paper, 1981

Figure 9.–Federal Obligations for R&D by NASA, DOE, NSF, and Other Selected Agencies—1966.78 (in millions of constant dollars)



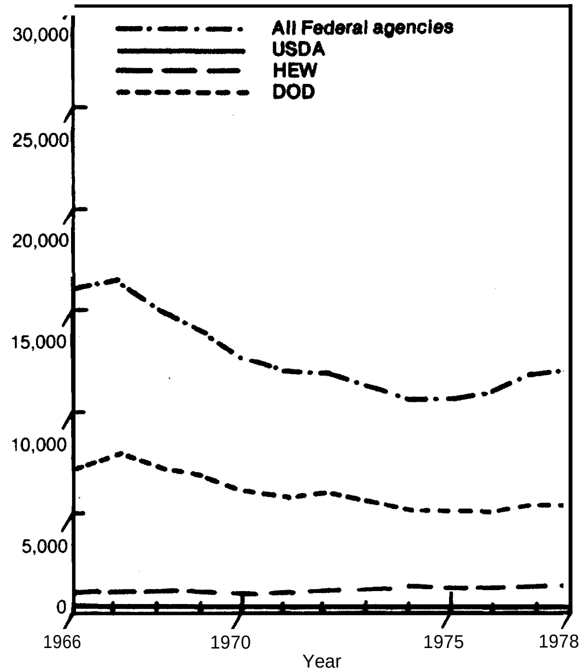
SOURCE Joseph Havlicek, Jr , and Daniel Otto, "Historical Analysis of Investment in Food and Agricultural Research in the United States, " OTA background paper, 1981

Figure 10.— Federal Obligations for R&D by USDA, DOD, HEW, and All Federal Agencies—1966-78 (in millions of current dollars)



SOURCE Joseph Havlicek, Jr , and Daniel Otto, "Historical Analysis of Investment In Food and Agricultural Research in the United States, " OTA background paper, 1981

Figure 11.— Federal Obligations for R&D by USDA, DOD, HEW, and All Federal Agencies—1966-78 (in millions of constant dollars)



SOURCE: Joseph Havlicek, Jr, and Daniel Otto, "Historical Analysis of Invest. ment in Food and Agricultural Research in the United States, " OTA background paper, 1981

eludes pass-through funds to the States, increased steadily by 149 percent from 1966 to 1978, and in constant dollars by 10 percent. Finally, the current-dollar Federal obligations for all R&D for all Federal agencies increased 72 percent from 1966 to 1978, but in constant dollars this ended up being a 25-percent decrease. The pattern in the expenditures for all R&D for all Federal agencies and the patterns in R&D expenditures of NASA and DOD, the two largest agencies in terms of R&D funding, are quite similar,

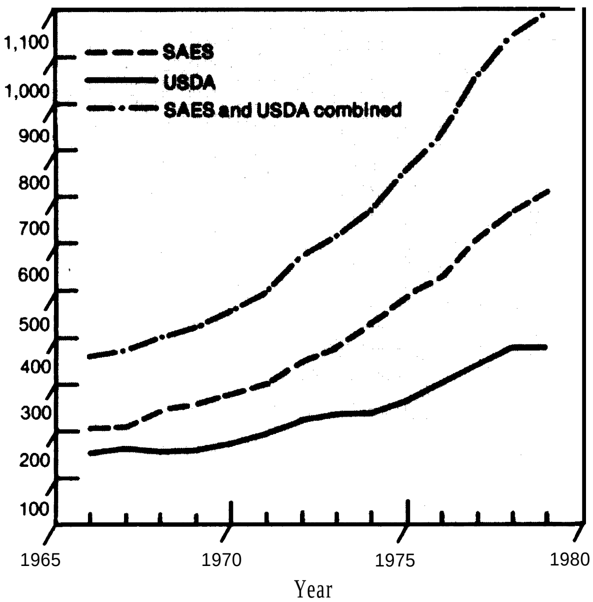
R&D Expenditures for U.S. Agricultural Research

Current dollar expenditures on total agricultural research for USDA, SAES, and USDA and SAES combined for the 1966-79 period are presented in figure 12, and the constant-dollar expenditures are shown in figure 13. The top line in each figure represents the expenditures of USDA and the SAES combined—i.e., the funding of public agricultural research in the United States. In current dollars, the total funding for public agricultural research increased 204 percent for the 14-year period. Total research expenditures in the SAES increased 245 percent during this period, while USDA expenditures increased only 149 percent.

But the funding picture shown in figure 13 is quite different, For this figure, expenditures were adjusted to 1967 constant dollars (deflated). The increase in the purchasing power of the total SAES and USDA agricultural research expenditures increased only 23 percent from 1966 to 1979. Furthermore, the constant-dollar agricultural research expenditures of USDA for in-house research increased only 1 percent during this period, while those in the SAES increased 40 percent.[1] Clearly, during this time and particularly during the latter part of the period, inflation severely eroded the purchasing

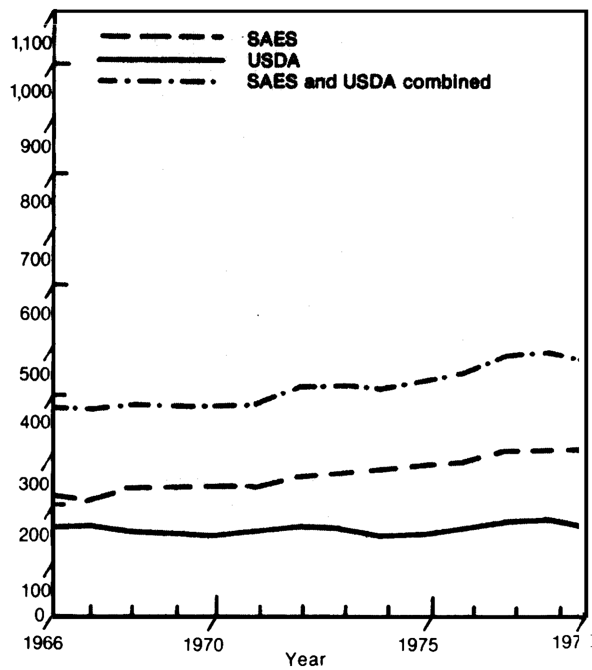
[1] The USDA figures exclude pass-through funds to the States. For further information see Havlicek and Otto, 1981.

Figure 12.–SAES, USDA, and Combined SAES and USDA Total Research Expenditures—1966-79 (in millions of current dollars)



SOURCE: Joseph Havlicek, Jr., and Daniel Otto, "Historical Analysis of Investment in Food and Agricultural Research in the United States," OTA background paper, 1981,

Figure 13.—SAES, USDA, and Combined SAES and 'USDA Total Research Expenditures—1966-79 (in millions of constant dollars)



SOURCE: Joseph Havlicek, Jr., and Daniel Otto, "Historical Analysis of Investment in Food and Agricultural Research in the United States," OTA background paper, 1981.

power of agricultural research funds. Moreover, the constant-dollar expenditures of USDA remained at about the same level during the period, so that the modest increase that occurred is attributable to SAES expenditures. During the 1966-79 period, SAES expenditures accounted for an increasingly greater share of public agricultural research funds.

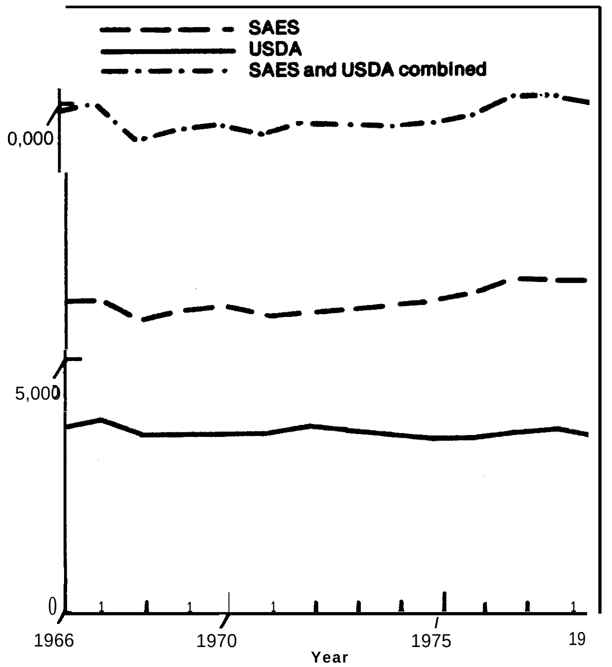
Scientific Manpower

During the same 14-year period, USDA scientist-years devoted to agricultural research remained nearly constant after a slight decrease from 1967 to 1968 (fig. 14). In the SAES there was a very gradual upward trend in the scientist-years in agricultural research, and the total increase from 1966 to 1979 was approximately 460 scientist-years. Increases in expenditures on agricultural research by USDA and SAES have basically been used to cover the salaries, supporting research equipment, and supplies for a nearly constant scientist manpower force. Yet during this same period, the demands on agricultural research have been greater than ever.

This is an acute problem in the strong research demand areas such as genetic engineering. The new demand for research manpower, especially from the private sector, creates problems for Federal agencies and especially universities in keeping staff and maintaining graduate programs in the field.

While USDA scientist numbers remain relatively constant, the average age is increasing. Between 1969 and 1976, the number of Science and Education Administration-Agricultural Research (SEA-AR) scientists 50 years of age and older increased from 28 to 39 percent of the work force; the number of those 30 years of age and under decreased from 9 to only 2 percent in the same period. By way of comparison, at the National Institutes of Health (NIH) the number of scientists 50 years of age and over (1976) was 15 percent,

Figure 14.—SAES, USDA, and Combined USDA and SAES Scientist Years–1966-79



SOURCE Joseph Havlicek, Jr , and Daniel Otto, "Historical Analysis of Investment in Food and Agricultural Research in the United States," OTA background paper, 1981

and 30 years of age and under was 25 percent. The average age of SEA-AR scientists in 1976 was 47 and of NIH, 35 (General Accounting Office, 1976, 1977). Most research institutions desire a continuous influx of young scientists in their organization.

Both personnel ceilings and shortage of funds are valid reasons given for these trends. Since both will probably remain as constraints in varying degrees in the near future, especially personnel ceilings, some management practices need to be established that will assure attraction and hiring of capable young scientists in SEA-AR.

USDA Expenditures

The agricultural research expenditures in current dollars of the major agencies within USDA are presented in figure 15 and the corresponding constant-dollar expenditures in figure 16. For the period 1966 to 1979, the Agricultural Research Service (ARS) was by far the largest component in terms of expenditures on agricultural research. In current dollars, ARS expenditures on agricultural research increased 139 percent from 1966 to 1979, but in constant dollars decreased about 3 percent.

Except for slight decreases from 1967 to 1968 and 1969 to 1970, the current-dollar expenditures on agricultural economics research by the Economics and Statistics Service (ESS) increased rather steadily during the 14-year period, and there was a 127-percent increase from 1966 to 1979. However, this increase did not keep up with inflation, and in constant dollars there was an 8-percent decrease from 1966 to 1979.

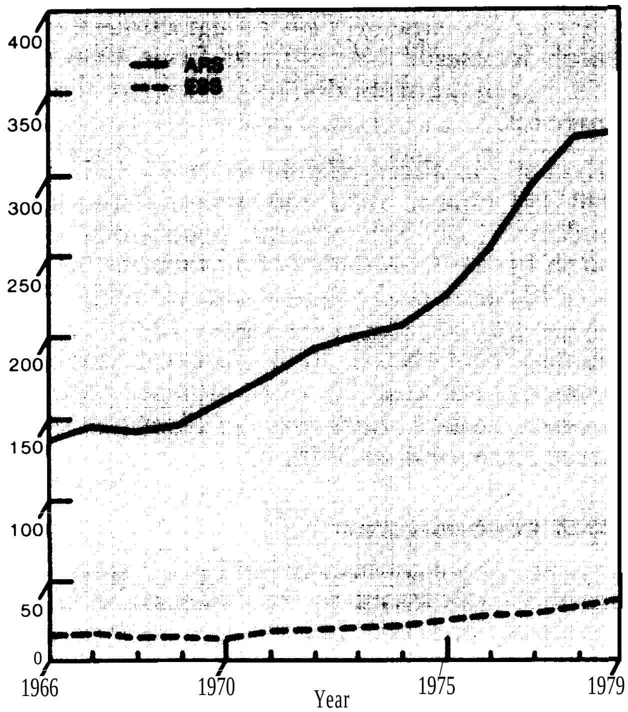
SAES Expenditures

Levels of expenditures on agricultural research by the SAES for the 1966-79 period, according to major components of Federal research funds, are presented in current dollars in figure 17 and in constant dollars in figure 18. The largest component from Federal sources was the total of the formula funds, including Hatch and other appropriations. In current dollars, these expenditures steadily increased from 1966 to 1979; the 1979 level was nearly 200 percent greater than the 1966 level. However, in constant dollars, the current-dollar increase translates to a 20-percent increase, or an average increase of about 1.5 percent a year.

Cooperative grants and cooperative agreements were the smallest component of Federal funding of agricultural research in the SAES. In current and constant dollars, these funds declined from 1968 to 1971, but since then have been increasing. Over the entire 14-year period, the current-dollar expenditures increased 197 percent, while the constant-dollar expenditures increased only 20 percent.

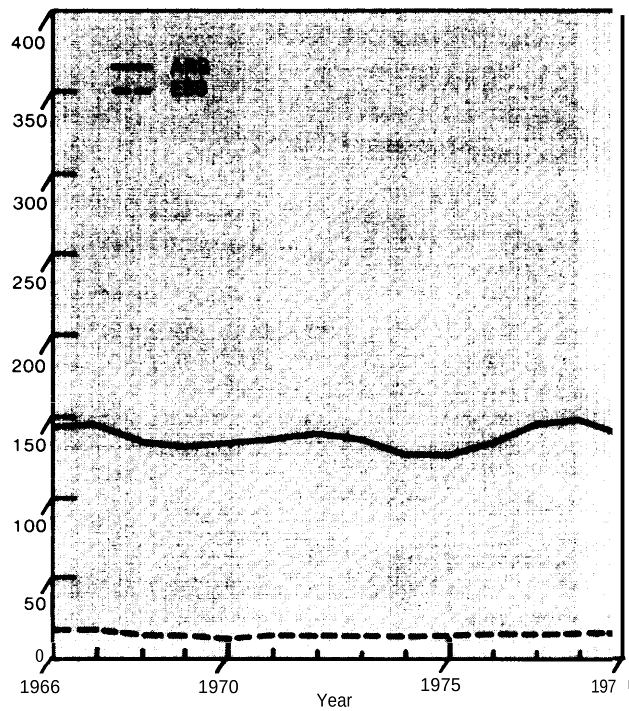
Other Federal funds for agricultural research at the SAES are one-half to one-third of the size of formula funds, but two to three times the size of expenditures from cooperative grants and cooperative agreements.

Figure 15.–USDA Research Expenditures by ARS, ESS—1966-79 (in millions of current dollars)



SOURCE: Joseph Havlicek, Jr., and Daniel Otto, "Historical Analysis of Investment in Food and Agricultural Research in the United States, " OTA background paper, 1981.

Figure 16.—USDA Research Expenditures by ARS. ESS—1966-79 (in millions of constant dollars)



SOURCE: Joseph Havlicek, Jr., and Daniel Otto, "Historical Analysis of Investment in Food and Agricultural Research in the United States, " OTA background paper, 1981

These other Federal funds have been an important source of funds to the SAES. With some variation, the current-dollar expenditures increased by 129 percent from 1966 to 1979, but in constant dollars this was an overall 7-percent decline.

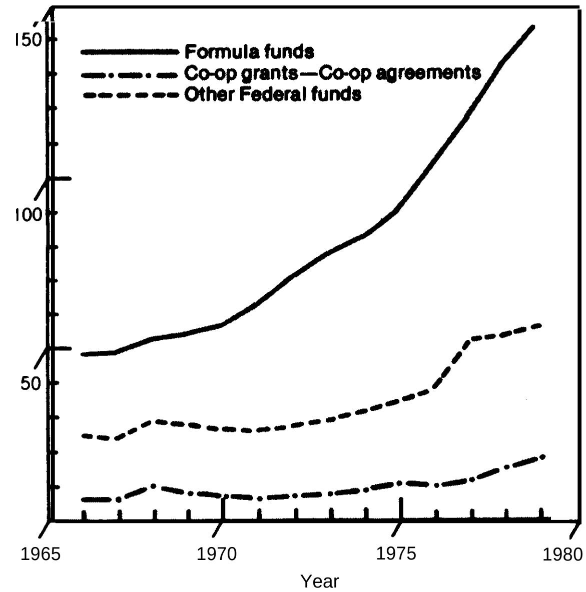
The major source of agricultural research funding at SAES is State appropriations and sales. Expenditures from these sources, private sources, and formula funds from Federal sources are presented in current dollars in figure 19 and in constant dollars in figure 20. In current dollars, all three sources increased during the 1966-79 period. State appropriations and sales increased nearly fourfold, resulting in a constant-dollar increase of 57 percent.

Private research funds for agricultural research at SAES are small relative to State appropriations and sales and the Federal formula funds. Nonetheless, they have steadily increased since 1966 and are becoming an important source of agricultural research funds. During the 1966-79 period, private sources of agricultural research funds going to SAES also increased fourfold in current dollars, which resulted in a constant-dollar increase of 63 percent.

Private Industry Expenditures

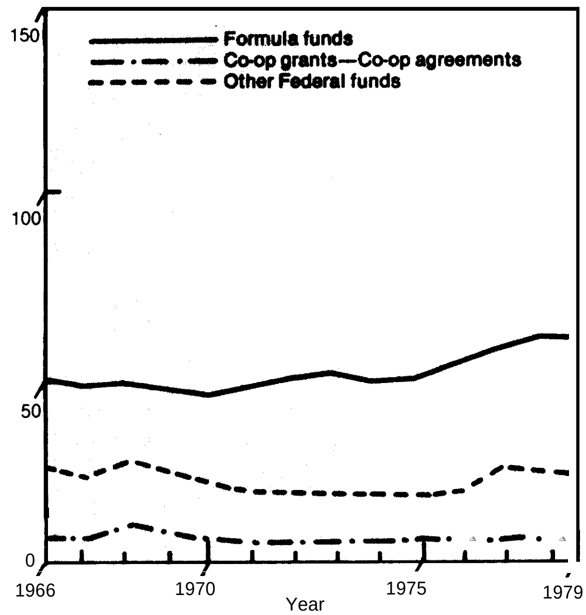
Data on the expenditures for agricultural research by private industry are considerably more limited than those on SAES and USDA. Some data concerned with applied research and development for agricultural-related products obtained from the Surveys of Science Resources Series of NSF are presented in figure 21. The time period covered is 1963 to 1975. In current dollars, the 1963 total expenditure by private industry for agricultural research was about $220 million, and increased to slightly over $600 million in

Figure 17.—Formula, Cooperative Grants and Cooperative Agreements, and Other Federally Funded Research Expenditures at SAES–1966-79
(in millions of current dollars)



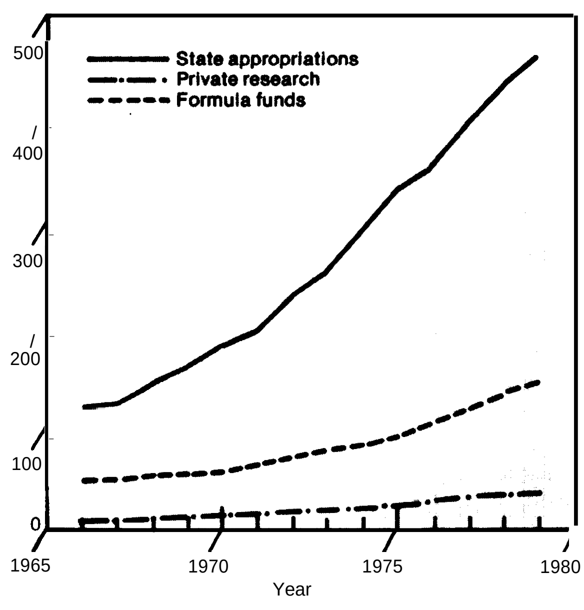
SOURCE: Joseph Havlicek, Jr., and Daniel Otto, "Historical Analysis of Investment in Food and Agricultural Research in the United States," OTA background paper, 1981

Figure 18.—Formula, Cooperative Grants and Cooperative Agreements, and Other Federally Funded Research Expenditures at SAES–1966-79
(in millions of constant dollars)



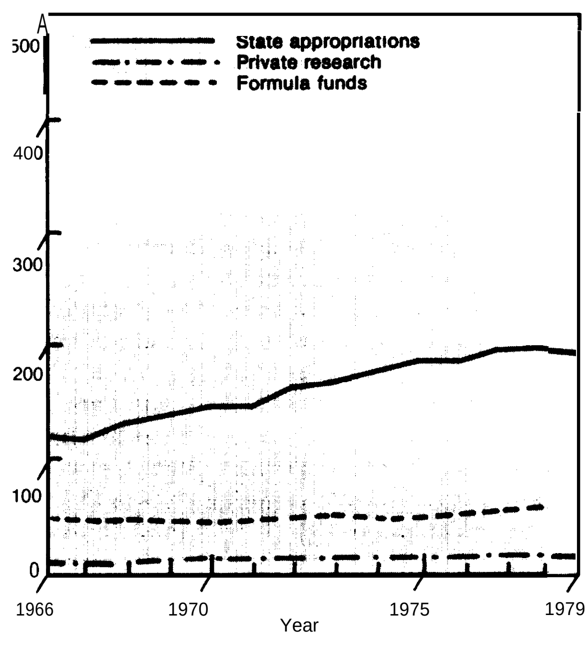
SOURCE' Joseph Havlicek, Jr , and Daniel Otto, "Historical Analysis of Invest. ment in Food and Agricultural Research in the United States, " OTA background paper, 1981.

Figure 19.—State Appropriations, Private Research, and Formula Funds at SAES—1966-79
(in millions of current dollars)



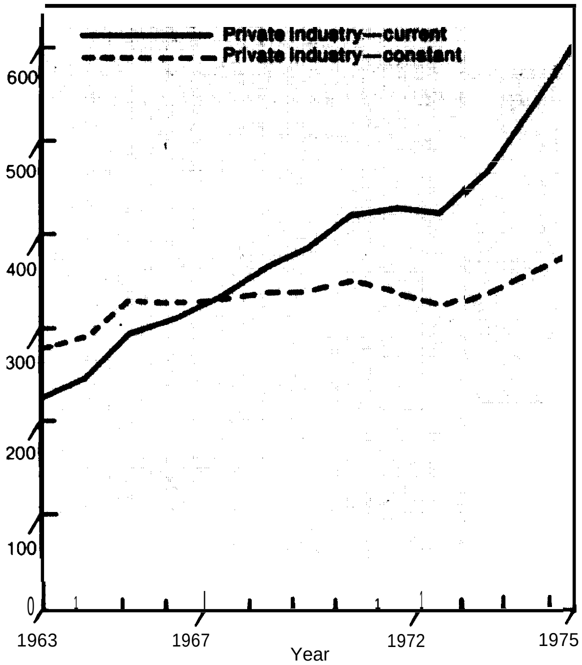
SOURCE: Joseph Havlicek, Jr., and Daniel Otto, "Historical Analysis of Investment in Food and Agricultural Research in the United States, " OTA background paper, 1981.

Figure 20.—State Appropriations, Private Research, and Formula Funds at SAES—1966-79
(in millions of constant dollars)



SOURCE: Joseph Havlicek, Jr., and Daniel Otto, "Historical Analysis of Investment in Food and Agricultural Research in the United States, " OTA background paper, 1981.

Figure 21 .—Total Expenditures for Applied R&D for Agricultural. Related Products by Private Industry—1963-75 (in millions of current and constant dollars)



SOURCE. Joseph Havlicek, Jr., and Daniel Otto, "Historical Analysis of Investment in Food and Agricultural Research in the United States, " OTA background paper, 1981,

1975—about a 170-percent increase. In constant 1967 dollars, this is a 39-percent overall increase or a 3-percent average annual increase.

A second, even less comprehensive source of data on private agricultural research, was obtained from a separate survey of agribusiness firms conducted by the Agricultural Research Institute (ARI) for 1975. The estimated research expenditures by agricultural firms for 1975 from this survey were $575 million, which is slightly less than the $602 million estimated from the NSF survey for 1975. The categories from the ARI survey are not strictly compatible with those of the NSF survey, so that direct comparison of the two surveys is not possible. However, similarities of the estimated overall level of private research from these two sources help substantiate the NSF figures as reasonable estimates of the level of agricultural research being conducted by private firms.

To get some perspective about relative magnitudes, in 1975 the total expenditure by private industry on applied R&D for agricultural-related products was about 72 percent of the total public expenditure (SAES and USDA combined) on agricultural research. This total expenditure by private industry in 1975 was approximately 23 percent greater than the SAES expenditure on agricultural research and about 75 percent greater than USDA's.

BENEFITS AND BURDENS

Research benefits must be evaluated in relation to whatever costs society must pay for them—whether in dollar investment, environmental impact, or whatever. In some cases these benefits have varying effects on producers and consumers. Researchers and their institutions also may reap benefits in terms of increased support. Likewise, State research may generate spillover benefits that accrue to residents of adjacent States or similar agroclimatic regions. In many cases, the degree of return from the research investment may influence decisionmakers as to the level of support that seems appropriate for future programs.

Nature of Benefits

People individually and collectively strive to improve their well-being, and research contributes to this societal goal. Benefits may be classified as primary (a direct result of research) and secondary (developed indirectly from the basic research activity). In addition, research produces certain questionable benefits or, in some cases, actual burdens to society, the degree of which may vary from slight to moderate, depending on individual evaluation.

Primary Benefits

Primary benefits include improved productivity, conservation, preservation, and reasonable costs of food and fiber.

The greatest emphasis in production research has been to improve crop varieties and breeds of livestock and poultry. In addition, research on purchased inputs has developed fertilizers with improved nutrient content, new and improved agricultural chemicals, and dramatic changes in farm machinery and equipment.

For the period 1945-79, technological innovations increased agricultural output 85 percent, but there was no change in the aggregate level of agricultural inputs (USDA, 1980). Substantial evidence shows that the rate of return on food and agricultural research investment is high relative to most other social investments (Evenson, Waggoner, and Ruttan, 1979). Therefore, the total volume of all goods and services is greater as a result of research investment than it would be if these funds had been invested in other alternatives.

Marketing research has made more food available through improved processing and fabrication, upgrading products, preventing waste, and providing for the use of products previously not considered viable.

Marketing research designed to reduce losses in quantity and quality of food obviously has an impact on the availability of food and its cost to consumers. Prevention of food waste by appropriate preservation and processing methods constitutes a large potential source of food. Research on reducing loss caused by pests results in estimated savings of $1.5 billion annually in the United States (National Academy of Sciences (NAS), 1977). Reducing the storage and transportation losses of fruits and vegetables could increase the supply of these products from 15 to 30 percent (NAS, 1977).

A reduction of the relative real costs of food and fiber results from conducting research at all stages of production, processing, storage, and distribution. In the United States, this reduction is quite substantial compared with that in other countries. For example, in 1977 only 16.5 percent of U.S. disposable income went for food, tobacco, and beverages (Mackie and Allen, 1980). In Canada, the figure was 21 percent. Elsewhere, spending on food, beverages, and tobacco ranged from 25 to 50 percent of total expenditures in high-income countries of Europe and Asia; around 45 to 50 percent in centrally planned countries; and between 40 and 65 percent in developing countries (United Nations, 1978). Note that all high-income nations spend less of their income on food than poorer nations.

Improved technology generated by research usually leads to relatively lower costs for farm products. This effect is brought about by supply and demand factors. On the supply side, the technology expands output. On the demand side, the expanded supply generally leads to relatively lower prices.

In terms of production, there is usually little point in a farmer adopting a new technology unless it reduces per-unit production cost, meets a regulation, or is for some personal reason such as reducing drudgery. The rate of adoption of new technology, in whole or part, is usually influenced by profitability.

The price factor represents the other side of the equation. As total output expands because of the adoption of the new technology, prices fall relatively. The rate and extent to which they fall depends on the price elasticity of demand. The domestic price elasticity of demand for most agricultural products is quite low, which means that a given increase in supply will bring about a substantial decrease in price. This has little effect on the early adopter of the technology, because his individual production is too small to affect the overall price level. But as the technology is widely adopted by other farmers, prices will drop relatively.

The effect of this general relative price decline on the individual farmer will depend on the degree to which he has adopted the cost-reducing technology. Those who have adopted it will be able to bear some reduction in price, although this will reduce their earlier profits. Those that have not adopted the technology will be disadvantaged because their costs have not been lowered. To the extent that the price decline is greater than the reduction in costs, all farmers will be disadvantaged. As prices go down, consumers will receive the advantage.

In a report on agricultural production efficiency, NAS concluded that: "Between 1950 and 1971, U.S. farm output increased 50 percent, while consumer prices remained relatively stable. If the same farming methods had been used in 1971 as in 1950, an equivalent abundance of food and other products coming from the farm would have cost consumers two to three times more than they did" (1975, p. 188).

Changes in the marketing and distribution of food have been significant in the last 30 years as evidenced by the expansion of supermarkets, which have reduced by 15 to 25 percent the retail cost of food to consumers (Kramer, 1973). These cost savings were made possible by labor reduction through self-service and large-volume operations in transportation, storage, and distribution.

Secondary Benefits

From the primary objectives of research flow secondary benefits, which include improved human nutrition, improved food quality and safety, an international trade balance, expansionary impacts on other sectors of the economy, release of labor to other sectors of society, and increased leisure time.

Research on food quality and safety and human nutrition results in: 1) better understanding of human nutrition needs; 2) improved diets and nutrition for individuals; 3) safer methods of food processing, preservation, and preparation; 4) reduced costs through knowledge of nutritional content of food and through food preservation; and 5) improved understanding of food additives and food contaminants.

Although malnutrition was discovered in certain disadvantaged groups within the United States during the 1960's, the widespread introduction of feeding programs such as Women, Infants, and Children (WIC), school breakfast and lunch, and food stamps seems to have done much to eliminate overt malnutrition, especially in children. The principal group that is apparently suffering the effects of poor nutrition because of low income is the elderly, who receive their benefits in a nondirected form.

Income is positively correlated with nutritional status in the absence of food entitlement programs; the low-income groups have the least adequate diet and the greatest vulnerability to malnutrition. The prime causes of inadequate nutrition are lack of knowledge on nutritional requirements and nutritive content of foods, the unavailability of food, and the financial inability to purchase it. Food choices also are influenced by socioeconomic and cultural factors such as family lifestyle, health, and age of individuals and outside influences, including mass media, advertising, and food labeling. Research that provides better insight into the impact of these factors on the nutrition and health of various population groups benefits consumers. Both agricultural production technology research and post-harvest food technology research affect directly the nature and distribution of these benefits among groups of consumers.

A major benefit from food and agricultural research is the positive contribution of agricultural commodities to the U.S. international trade balance. An increasing volume of food exports from the United States has partially offset the rising volume of imports of oil and manufactured goods. In essence, agricultural commodities have provided much of the exchange necessary for the United States to import oil and manufactured goods. An increasing output of agricultural exports—necessary to sustain imports—is subsequently dependent on a continuous flow of production technology. Research and education undergird the advancement of production technology and sustain the strong competitive position of the United States in international food and fiber commodities markets.

Table 1 provides documentation for the importance of agricultural commodities in reducing the magnitude of the U.S. international trade balance. Agricultural exports increased from $7.2 billion in 1970 to $41.2 billion in 1980. The trade balance in agricultural commodities increased from $1.5 billion in 1970 to $23.8 billion in 1980. This contrasts with a rising international trade deficit in other commodities from a surplus of $1.2 billion in 1970 to a deficit of $48,6 billion in 1980. An international trade deficit places a downward pressure on a national currency, reduces gold reserves, provides exchange for alien ownership of physical assets, and contributes to national price inflation. These undesirable economic consequences lead in turn to a reduced standard of living and chronic high levels of unemployment.

A favorable trade balance in agricultural commodities contributes directly to the well-being of American farmers and commodity processors, handlers, and transporters. It also contributes to the well-being of American consumers by providing exchange for imports; and it lends stability to the American economy.

Table 1 .—Exports, Imports, and International Trade Balance in Agricultural and Other Commodities in the United States (in billions of dollars)

	Exports		Imports		Balance	
Year	Agricultural	Other	Agricultural	Other	Agricultural	Other
1950. .	$ 2.9	$ 7.3	$ 4.0	$ 4.8	($ - 1.1)	$ 2.5
1955. ,	3.2	12.2	4.0	7.4	(- 0.8)	4.9
1960. .	4.8	15.5	3.8	10.8	1.0	4.7
1965. .	6.2	20.9	4.1	17.3	2.1	3.6
1970. .	7.2	35.3	5.8	34.2	1.5	1.2
1975. .	21.9	84.2	9.5	86.6	12.4	(- 2.4)
1979. .	34.7	143.8	16.9	189.4	17.9	(- 45.6)
1980. .	41.2	175.2	17.4	223.8	23.8	(- 48.6)

SOURCE. Business Statistics, Biennial Edition. United States Department of Commerce, Off Ice of Business Economics,1961 and 1977. Survey of Current Business. United States Department of Commerce, Bureau of Economic Analysis, April 1980, vol. 60, no. 4. Agricultural Outlook, U .S. Department of Agriculture, March 1981

Expansion of food and agricultural production contributes to economic growth in two ways, First, a change in agricultural production is directly related to changes in that sector's development. For example, technological innovations cause a direct change in farm earnings, net farm income, farm-labor requirements, and hence farm earnings. Second, this change rebounds throughout the economy to produce changes in income in other sectors. Thus, food and agricultural research that results in changes in output of the agricultural sector has expansionary impacts on other sectors of the economy and attendant changes in incomes.

Although farm production continued to increase dramatically during the 20th century, the farm labor input reached a peak of 13.6 million farmworkers in 1916 and subsequently declined to less than 3.8 million in 1979 (USDA, 1980). This release of farm labor provided the labor necessary to implement and expand other economic sectors.

However, a substantial part of the labor displaced by increased productivity on the farm was needed for off-farm activities in the food and agricultural sector. Under the advancing technology in farm production, progressively larger quantities of farm inputs were purchased from the industrial sector. Today, the food and agricultural sector accounts for about 20 percent of total employment and 20 percent of total national income compared with an estimated 35 to 40 percent of total employment and national income in 1940.

Much of the increasing labor productivity in the food and agricultural sector is reflected in the small proportion of consumer income spent for food as noted earlier. This means that the remaining income is freed to apply toward other human wants.

One of the less quantifiable and less documented benefits of food and agricultural research is the reduction of drudgery and the increasing leisure time of farm operators and workers. Although these kinds of benefits do not carry monetary value, they are important in the advancement of the welfare of society. Such benefits have also been extended to workers in food-fiber processing, fabrication, storage, and distribution.

In some cases, output of farm products per unit of farm-labor input has increased up to 80 times what it was at the beginning of the 20th century (Cochrane, 1979). Increasing labor productivity on the farm is reflected in both the output per unit of labor input and a reduction in the intensity of the labor input. The increasing labor productivity also has provided more leisure time for the individual worker.

Uncertain Benefits and Burdens

One of the least documented effects of agricultural research has been its impact on environmental quality. Agriculture produced undesirable environmental side effects long before the rapid advance in agricultural production techniques that characterized agriculture in the second and third quarters of the 20th century. Much of the early cotton and tobacco farming in the South resulted in soil erosion, widespread silting of streams, and changes in ecosystems. Farmwork animals produced large amounts of waste that entailed health hazards to farm families because of inadequate methods for controlling pests attracted to such waste. The dust storms in the Plains States resulted in major environmental threats from attempts to cultivate marginal lands with inadequate soil and crop management technology.

It is still an open question as to whether, on balance, the modernization of agriculture has given rise to more environmental problems than it has solved. Ruttan (1971) and Schultz (1974) proposed that the technological advances of agriculture have enlarged measurably the biological possibilities of the natural environment, allowing us to eventually have more agricultural output and more environmental quality components. The development of agricultural technology and the resultant growth in agricultural productivity have allowed substantial reductions in the acreage of major crops such as corn, wheat, and cotton. Much of the reduced acreage came from marginal lands highly subject to soil erosion, and the return of much marginal cropland to pastures and forests reduced many of the kinds of environmental hazards arising from agriculture in the past (White, Eddleman, and Purcell, 1980).

The current environmental problems attributed to agriculture largely involve pest control practices, silt and water management systems, feed-lot waste disposal, and disposal of residue from food- and fiber-processing activities. Certainly these environmental problems are more widespread than those of the past. Agricultural technology has changed the form and place of the threats, and perhaps the number of people exposed to these threats. The most controversial issue pertains to the impact of chemical pesticides used for plant production and protection and of soil sedimentation on water quality.

Ruttan (1971) suggests that the failure to develop agricultural technology (e.g., pest control and soil management systems) that would minimize agriculture's impact on the natural environment resulted from an undervaluation of environmental resource amenities. In other words, the capacity of the natural environment to absorb the residuals from crop and livestock production has been treated as a free service. Scientific and technical innovations were overly biased toward the development of land substitutes (plant nutrients, chemical pesticides, and crop varieties and management systems) that reflected undervaluation of the social cost of the disposal of residuals from agricultural production processes. Recognition of undervaluation of the social value of environmental services, coupled with regulatory actions by Federal and State governments, has led to redirection of agricultural research efforts in response to the rising economic value of environmental resource amenities, Examples of this redirection include: 1) integrated pest management techniques; 2) reduced tillage and no-till crop production systems and other soil and water conservation management systems; 3) waste-disposal systems using deep lagoons; 4) recycling processed animal wastes through the animal-plant-soil system, as fertilizer and animal feeds for ruminants; 5) aquatic weed control techniques; 6) methods for disposal of urban-produced sewage and digested sludge on agricultural and forest land; 7) organic farming techniques; and 8) alternatives to burning grasslands for seed production and croplands for excessive crop residue removal, The aim of these research efforts is to maintain agricultural productivity and profitability while substantially reducing deterioration of the natural environment caused by agricultural production and processing activities. Agricultural producers and processors, as well as the public, are beneficiaries of this research.

Burdens

Farmers who are nonadopters of technology may rightfully regard some research as a burden, As the prices of farm products decline when more farmers adopt a cost-reducing technology and thereby increase supply, those who have not adopted the technology will be disadvantaged because their costs have not been lowered,

With the adoption of mechanization, labor efficiency has advanced, thus releasing labor from the agricultural sector to provide an array of higher order goods and services. Labor displacement and individual hardships have occurred in the process. Migration of unskilled persons from farms to cities has contributed to urban ghettos that persist to this date.

There have been few burdens from food and agricultural research on the consumer. One of the perceived problems is a result of the rapid changes that such research has brought to the growing, processing, and packaging of food. The use of inorganic chemicals in these processes is looked on with disfavor by certain segments of Society Others disavow highly processed food products in favor of more “natural” foods. Food attitudes are deeply rooted even in a technological culture such as prevails in the United States.

Transportation and storage requirements of our food distribution system have made necessary the development of varieties resistant to bruising and with long shelf life. Some sensory qualities were relinquished in order to achieve this. However, most consumers are not aware of this when they complain that the January supermarket tomato does not corn-pare to the one grown in their backyard in July.

Distribution of Benefits and Burdens

Analysis of the flow of benefits from food and agricultural research focuses primarily on the distribution of benefits between domestic producers and consumers. The analytical framework is the concept of “economic surplus,” partitioned into that which accrues to buyers (consumer surplus) and that which accrues to sellers (producer surplus).[2]

Farm Producers

Benefits from agricultural research have different impacts on farms of different sizes and affect farmers according to how quickly they adopt new technology. Effects are determined by type of technology and often increase profits of some producers to the detriment of others. Technological advances in feed grain production, for example, would lower operating costs for beef, hogs, dairy, and poultry production.

Studies indicate that technology reduces per-unit production costs more on large farms than on small farms, indicating important economies of size (Jensen, 1977).

Technology affects farmers according to the speed with which new innovations are

[2] The concept of economic surplus as a measure of consumer and producer welfare is well-documented (Currie, Murphy, and Schmitz, 1971, Willig, 1976).

adopted. Cochrane (1958) grouped farmers into three categories—early adopters, followers, and laggards. Early adopters are able to increase their income with new technology that reduces cost of production. However, increased production resulting from new technology in the aggregate depresses prices, and followers gain less from it, Finally, laggards are forced to use the new technology in order to survive.

Effects are often determined by the type of technology. Certain mechanical innovations favor large-scale farms of the Corn Belt and Southwest over smaller farms in the South and East.

A technological change in the marketing sector, such as a reduction in waste or spoilage, affects the cost structure for marketing services. In such cases, retail and farm prices may be affected by reduced marketing margins. ” The farm price would be expected to increase and the retail price would be expected to decline with reduced marketing margins.

Competition in the marketing sector results in lower cost of marketing services being passed on to consumers or producers. The more competitive the industry, the less tendency there is for private research, because the benefits accrue to consumers and farmers. In a less competitive industry, private research is more profitable for the individual firm, and it may reduce the level of competition.

Technology that changes the relative productivity of resources shifts the distribution of income among resources (Heady, 1971). These changes have reduced the proportion of total farm income attributed to labor and increased the proportion attributed to capital. The impact of technological change on farmland's share of farm income is not easily determined.

*Both the derived supply at retail, dependent on farm supply and the marketing margin, and the derived demand at the farm level, dependent on retail demand and the marketing margin, would shift in a competitive market as a result of a reduction in marketing costs.

The demand for land is affected also by technological advances in agriculture. Herdt and Cochrane (1966) postulated that technological advance has benefited farmland owners, not necessarily farm operators. They said that farmers view technological change as reducing cost of production and hence are able to bid up the price of farmland accordingly.

Most improvements in agricultural production technology increase the productivity of capital and land relative to labor. They therefore generate incentives to substitute land and capital for labor. The story of the vastly increased capital requirements for successful farming is well-known. The decline in the relative importance of labor as a farm input also is well-known. Since many farmworkers owned only their labor, the value of their assets was decreased through innovations in production, and they were forced to look for alternatives. T. W. Schultz puts the actual outmigration of labor from American farms between 1930 and 1974 at 33 million people, the largest migration of modern times.

Many of those who migrated to the cities were able to make successful adjustments and obtain more productive and rewarding employment in nonfarm industries. However, for many the adjustments were painful and costly. The expanded pool of workers in the non farm sector depressed the nonfarm wage rate.

Many rural communities that served populous farming areas deteriorated as the number of farmworkers declined. The tendency for people to leave rural areas has affected the viability of many rural commercial enterprises, churches, community services, and in some cases entire communities.

Too little research was done on the processes of agricultural development as they affected rural America. Too often costs were ignored, especially if these costs were incurred in the migration to urban centers.

Consumers and the General Economy

As noted earlier, consumers benefit from food and agricultural research in many ways.

Some of these benefits appear to be concentrated among certain groups of American families. Agricultural research that improves the safety of food products is likely to affect consumers in all income categories, The benefits of such research include improved health and longer life.

The following analysis estimates the distribution of benefits from agricultural research on the basis of food expenditures. Family size and income characteristics for six income categories are shown in table 2. The six income classes ranged from under $5,000 to over $20,000, and the average-size family ranged from 2,93 persons in the lowest income class to 3.79 persons in the highest. The present value of average benefits per family for the various income classes also is shown. These estimates may be interpreted as the benefits accruing to each family as a result of food and agricultural research expenditures in that year. Comparison of consumer benefits indicated that average benefits per family increased with the level of family income and ranged from $16.20 in the lowest income category to $30.74 in the highest.

The ratio of benefits to family income was almost four times higher for the lowest income class than for the highest, indicating that food and agricultural research has a greater beneficial impact on low-income families than on high-income families in relation to family income. This conclusion supports the hypothesis that agricultural research tends to modify the existing income distribution in favor of the lower income strata (Pinstrup-Andersen, 1977).

The cost of food and agricultural research, as measured by production-oriented research expenditures, is reported on a household basis (table 3). Total agricultural research costs per household ranged from $1.31 for the lowest income class, under $5,000, to $25.60 for the highest, over $20,000. While benefits and costs increase with the level of income, tax incidence increases at a faster rate. Therefore, the benefit-cost ratio is highest in the low-income category. The benefit-cost ratio declined from 12.37 for low-income families to 1.20 for high-income families. Both benefits and costs of agricultural research expenditures tend to redistribute income from higher to lower income families. However, even those families in the highest income class receive net benefits from research investment on agricultural productivity.

Table 2.—Relationship Between Agricultural Food Research Benefits and Family Income

Income class (dollars)	Distribution of population (percent)	Average size family[b] (persons)	Average family income (dollars)	Average benefits per family[c] (present dollar value)
Under $5,000	18.190/o	2.93	$3,981	$16.20
$5,000-$8,000	14.14	3.15	7,922	19.06
$8,000-$12,000 . . .	21.17	3.28	10,528	20.63
$12,000-$15,000 . .	14.47	3.48	13,458	22.13
$15,000-$20,000 . .	16.07	3.68	17,371	25.91
Over $20,000	15.96	3.79	28,953	30.74

NOTE: These calculations represent an Investment in 1974 that will have its impact in 1987.

[a]Anthony E. Gallo and William T. Boehm, "Food Expenditures by Income Group," *National Food Review*, NFT-3, USDA, ESCS, Washington, D. C., June 1978.

[b]U.S. Department of Commerce, Bureau of the Census, *Current Population Reports*, Series p-60, no. 101, "Money Income in 1974 of Families and Persons in the U.S," US. Government Printing Office, Washington, D. C., 1976.

[c]Total consumer benefits are calculated according to the equation

$$TB_C = 1/2 \times MVP_R \times RE \times D$$

where TB_C is total consumer benefits from agricultural-food research; MVP_R is marginal value product of research (Davis), RE is production-oriented research expenditures in 1974 (Budget of the U.S. Government; USDA, *Inventory of Agricultural Research;* U.S. Department of the Treasury); and D is the discount factor over 13 years at 10°/0 (Lu, Cline, and Quance). Total consumer benefits are allocated to income classes according to the level of food expenditures

"These calculations represent an Investment in 1974 that will have its impact in 1987.

SOURCE: Fred C White, B. R Eddleman, and J. C. Purcell, "Nature and Flow of Benefits From Agriculture-Food Research," OTA background paper, 1980.

Table 3.—Relationship of Costs and Benefits of Agricultural Research to Family Income

Income class	Average family income[a]	Average benefits per family[b]	Federal taxes for agricultural research per family[c]	State taxes for agricultural research per family[d]	Total taxes for agricultural research per family[e]	Benefit-cost ratio[f]
Under $5,000	$ 3,981	$16.20	$ 0.43	$0.88	$ 1.31	$12.37
$5,000-$8,000	7,922	19.06	1.77	2.05	3.82	4.99
$8,000-$ 12,000	10,528	20.63	3.19	2.85	6.04	3.42
$12,000-$ 15,000	13,458	22.13	5.29	3.97	9.26	2.39
$15,000 -$20,000	17,371	25.91	8.40	5.59	13.99	1.85
Over $20,000	28,953	30.74	15.78	9.82	25.60	1.20

[a]U.S. Department of Commerce, Bureau of the Census, *Current Population Reports,* series P-60, no. 101, "Money Income in 1974 of Families and Persons in the U.S.," U.S. Government Printing Office, Washington, D. C., 1976,
[b]Expressed in present value. See table 2 for details of Calculation procedure.
[c]Production-oriented research expenditures for Agricultural Research Service, Economic Research Service and the Federal Government's Share of State Agricultural Experiment Stations are allocated among income groups according to the distribution of Federal personal income taxes (U.S. Advisory Commission on Intergovernmental Relations, 1974).
[d]State funded production.oriented agricultural research expenditures are allocated amOng income groups according to the distribution of State personal income and general sales taxes (U.S. Adwsory Commission on Intergovernmental Relations, 1974).
[e]Summation of Federal and State taxes for agricultural research Per family.
[f] Average benefits from agricultural research expenditures per family divided by total taxes for agricultural research Per family,

SOURCE: Fred C White, B R. Eddleman, and J C Purcell, '(Nature and Flow of Benefits From Agriculture-Food Research, " OTA background paper, 1980

Research investment in the food and agricultural sector has led to new products and technology that increased agricultural productivity and allowed labor to flow from the farm to the nonfarm sectors. These adjustments in the labor force have raised national income because average nonfarm income is typically above average farm income. Tweeten and Hines (1965) approximated the contribution of agricultural productivity changes since 1910 accruing to the national income in 1963. Estimates for the 1940-79 period were calculated using a similar procedure (table 4). With only 3.5 percent of the population living on farms in 1979, the actual national income was $1,924,8 billion. Assuming that farm changes had not taken place since 1940, and that in 1979 (as in 1940), 21.3 percent of the population had lived on the farm, national income would have been $111.8 billion (or 5.8 percent) lower.

Table 4.—Estimates of the Contribution of U.S. Agricultural Productivity Change to the 1979 National income Since 1940
(in billions of 1979 dollars)

Decade or years	Contribution to 1979 national income
1940-50	$44.6
1950 -60.	36.6
1960-70 . . . .,	24.6
1970-75	2.9
1975-79	3.1
Total 1940-79	$111.8

SOURCE Fred C. White, B R Eddleman, and J C Purcell, "Nature and Flow of Benefits From Agriculture-Food Research, " OTA background paper, 1980.

Effect on Social and Economic Organization

Technological changes have thus had far-reaching effects on the development of rural America. In retrospect, the food and agricultural research institutions have not been as alert as they should have been in anticipating these effects and in developing means of coping with undesirable effects. As a minimum, the secondary effects of changes associated with the application of knowledge generated through the food and agricultural research programs should be identified. This is difficult to do because of the pervasiveness of the effects.

On occasion, scientists have called attention of the public to special social problems that would occur as a result of scientific breakthroughs. An example of this is the development of the cottonpicker which scientists knew would replace a large number of workers in the South (Johnson, 1952). This was well-publicized prior to the full impact which released thousands of workers and resulted in migration to the cities for those who could no longer find work on the farm.

It was erroneously assumed that development of technology to enhance the supply of products would automatically enhance national well-being and that a desirable economic and social structure would be worked out through the market forces. In many instances, this did not follow. Serious problems of national consequence emerged that were largely external to the specialized systems of research and decisionmaking, which led to the development and introduction of the new technology.

The continuing concern over urban and rural development, resource conservation, environmental quality, structure of agriculture, and the quality of life generally derives from other than fear of inability to produce sufficient food and agricultural products to meet national needs. The food and agricultural institutions in this country have demonstrated beyond question their efficiency in generating and applying knowledge to achieve increased production of commodities.

The concerns over national development derive largely from the social costs of technological development that have been largely ignored in the past. They reflect continuing questions with respect to how people fare under conditions of national economic growth.

Fundamental questions concerning these social issues are important. Can the answers to these concerns be consistent with reasonably efficient production of goods and services? If not, what kind of tradeoffs appear possible and desired? Conflicts, real or imagined, must be recognized and studied, and rational conclusions must be reached.

Public food and agricultural research institutions were not created to chart a course for national development. Indeed, they are ill-suited to do so. However, as centers of learning, dedicated to the discovery of truth, they do have a responsibility to examine critically the functioning of American society, to explore alternatives, and to interpret their findings to the people. This is a most important responsibility. Unless it is done well, the quality of life is likely to be treated as secondary to the problems of organization for the production of goods. Even when done well, it is the responsibility of the people through their elected officials to articulate the decisions and programs desired.

Researchers and Research Institutions

Researchers and research institutions can, in a sense, benefit from the results of research. Sometimes research is perceived to be directed for the benefit of the individual researcher or the institution. When this is the case, research tends to be self-serving.

Administrators of public agricultural research agencies are motivated to optimize some combination of continuing institutional budget support and discretionary funds from State sources or from Federal and private grant sources. These discretionary funds are often used to support the more basic research that has a longer term payoff both in terms of the productivity of the applied research (Evenson, Waggoner, and Ruttan, 1979) and in the prestige of the research agency.

To the extent that the research efforts are successful and appropriate, recognition accrues to the agency or scientist conducting the research, and further increases in support in terms of institutional and discretionary funding are assured. In this sense, both public research agencies and the scientists conducting the research are direct beneficiaries of the results of the research. (For further discussion on this point see White, Eddleman, and Purcell, 1980).

Benefits and Funding Sources

In State government funding, food and agricultural research financed by one State may benefit or harm the residents of other States. * For example, an improved crop variety developed in one State may be adopted in neighboring States to increase yields and total production. However, in some cases an action by a State may adversely affect residents of another State. Producers in regions other than where the improved crop variety was developed and where that particular variety would be unsuitable for adoption might pay lower prices as the result of increased aggregate production.

State boundaries do not coincide with homogeneous agricultural production regions. Research projects in one State, which are addressed to specific local problems, likely will produce results applicable to other States within the same homogeneous production region. Furthermore, knowledge gained from public research is disseminated without regard to geographic boundaries.

Spillover benefits generated by State A that accrue to the residents of State B generally are not accounted for by State A policymakers. The earlier argument concerning neglect of these external benefits has been that State A will provide a smaller level of research expenditures than would be efficient from society's perspective. Given the possibility of negotiation between States, State B may find it advantageous to pay A to increase its level of research activities. Such a subsidy will reduce A's research costs and lead to a higher level of research activities. The negotiation process likely will be complicated by the fact that spillovers flow in both directions between the two States. Furthermore, the outcome will depend on the relative bargaining strength of the two States and will not lead necessarily to an efficient solution to the external benefit problem (Musgrave and Musgrave, 1973).

*Benefits from scientific or technical progress, originating from a private firm or the public sector, that flow to other firms or consumers without compensation to the firm or public sector component originating the research are called externalities. Obviously, these effects may have either positive or negative impact.

If only a few States produce a given commodity, one of the States might conduct the research for it with the research effort supported by the other States. However, attempting to coordinate these activities involves decisionmaking costs that include the value of time, effort, and direct outlays related to the bargaining process. For those cases in which external benefits from agricultural research affect a large number of decisionmaking units, total decisionmaking costs of effective coordinated action are likely to be quite large. When the impact on consumers is considered, a large number of States would be concerned with almost all aspects of agricultural research.

When a public benefit equally affects the residents of the Nation, funding for such research can usually be provided more efficiently by the Federal Government.

Partial funding by the Federal Government affords one solution to attaining the nationally desired level of regional research expenditures. An often-used technique to increase State expenditures for government services is the matching grant, in which the recipient State government is required to match Federal funds with funds from its own sources according to some specified formula. While some Federal grants to States for food and agricultural research require matching funds, most States invest more in food and agricultural research than just that required to match grants.

The formula for matching funding should be based on the relative importance of external and internal benefits. If these grant programs are properly designed, they should direct State expenditures toward levels considered optimal from the viewpoint of society. An appropriate matching grant program obviously requires identifying and quantifying State benefits and spillovers from agricultural research expenditures. There have been some recent developments concerning the measurement of spillovers. Evenson, et al. (1979), estimated that, on the average, 55 percent of the change in productivity attributed to technology-oriented research was realized within the State conducting the research. The remaining 45 percent was realized in other States. Interregional spillovers of the benefits from food and agricultural research were estimated by White and Havlicek (1980) (table 5). These estimates indicate that the aggregate ratio of spillovers to regional benefits is 1.73. The Northeast and the Appalachian regions have the lowest ratio of spillovers to regional benefits. Four regions (Lake States, Corn Belt, Delta, and Southern Plains) have spillover-to-regional benefit ratios higher than 2 to 1.

The ratio of Federal to State expenditures for food and agricultural research and extension can be compared with the ratio of spillovers to regional benefits to determine whether the Federal Government actually financed the spillovers (table 5). * These results indicate that the Federal Government financed all of the spillovers in only three regions (Northern Plains, Appalachian, and Mountain). In aggregate, the ratio of Federal to State expenditures is only 1.38 compared to 1.73 for the ratio of spillovers to regional benefits. Thus, the Federal Government's contribution to production-oriented food and agricultural research and extension should be increased 25 percent to aline regional funding with regional benefits, on the average. Several regions would require a greater increase in Federal expenditures to yield an equitable distribution across all regions.

* Federal expenditures are not limited to those funds going to the SAES and cooperative extension services under formula and grant programs; they also include the funding of agricultural research in each region through the USDA agricultural research agencies of SEA / AR, USDA / ESS, and USDA / Soil Conservation Service.

Table 5.—Regional Estimates of External-to-Internal Ratios Related to Benefits and Funding of Production-Oriented Agricultural Research and Extension

Region	Ratio of spillovers to regional benefits	Ratio of Federal-State expenditures
Northeast	1.31	0.97
Lake States	2.73	1.10
Corn Belt	2.04	1.25
Northern Plains	1.40	1.63
Appalachian	1.19	1.60
Southeast	1.40	1.37
Delta	2.48	1.80
Southern Plains	2.80	2.10
Mountain	1.60	2.35
Pacific	1.89	0.90
Aggregate	1.73	1.38

[a] Includes Federal funding of production-oriented agricultural research and extension in each region through SEA/CR, SEA/Aft, SEA/EXT, USDA/ESCS, and USDA/SCS relative to State expenditures for agricultural research and extension in each region.

SOURCE: Fred C. White and Joseph Havlicek, Jr., "Interregional Spillover of Agricultural Research Results and Intergovernmental Finance." Paper presented at Symposium on Methodology for Evaluation of Agricultural Research, Minneapolis, Minn., May 12-13, 1980.

Private-Sector Funding Related to Flow of Benefits

One continuing issue is: Who captures the benefits from public sector and private sector research? Presumably, the issue relates to the question of whether a particular problem area should be addressed through public research if the gains from the research are embodied in private firms' products. In general, there are spillovers or indirect benefits from public-sector research to the private sector and from private-sector research to society. If the benefits from research can be captured by the private sector, there is an incentive for private firms to invest in R&D activities.

The private sector may invest in R&D activities in which spillover or indirect benefits accrue to society. No specific case studies have been made for the agricultural input or food-processing industries. a Studies by Mansfield, et al. (1977), Terleckyj (1974), and Griliches (1977) of the distribution of gains from private R&D in manufacturing and non-manufacturing industries indicate that the spillover effects are at least as large as the direct benefits going to the firms conducting the R&D. Thus, the social returns tend to be roughly double that of private returns to the investment. In this regard, substantial social benefits are derived from private industry investments in R&D activities.

The USDA (1979) assessment of post-harvest technology research identified four distinguishing characteristics of private-sector research in food processing, handling, and

[3] Some of the conceptual considerations, however, have been outlined in a note by Peterson, 1976,

marketing. These were: 1) most private-sector research tends to be focused on short-term applied problems for which there is expectation of an acceptable return on the research investment; 2) longer term basic inquiry into how biological, economic, and social systems function would not be picked up by the private research sector if it were dropped by the public research agencies; 3) even though there may be substantial social benefits from private research activities through spillover effects, private industry generally is not concerned with the concepts of consumer surplus or net social benefits from their research endeavors: and 4) most private firms are reluctant to reveal knowledge that might cause existing technologies or processes to become obsolete prior to extracting the flow of economic returns from past investments in these techniques. Thus, there is incentive to delay publication of knowledge possessing this potential impact, even if the research might have been carried out partially under the auspices of public funding.

Public-sector support for basic research generally benefits both society and the private sector. Since the results of basin research are difficult to internalize to any particuiar private firm without public support, underinvestment in basic research would result. However, in the case of applied and developmental research, the appropriate mix of public and private research investments becomes an important issue. The private sector will stand to benefit from public investments in those research outputs that are embodied in private-sector products.

Public R&17 may be justified on at least three grounds: 1) as a result of the spillover effects, substantial social benefits are derived from the mixture of public and private research; 2) in the absence of public-sector support, the direction of the research might be biased strongly toward proprietary mechanical and chemical technologies; and 3) for those situations where private research might have a detrimental effect on the structure of the industry (making a competitive structure noncompetitive, or a noncompetitive structure still more imperfect). A mix of public and private research may preserve competition or reduce the amount 01 concentration. The importance of this last basis for public research investments is that most competitive industries provide a larger quantity of the product at a lower cost to consumers than would be expected from monopolistic industry.

For many biological research activities, because of the ease of imitation and the lack of patent enforceability, it is likely that the private sector would substantially underinvest in R&D. Thus, much of the biological research is supported by the public sector, even in those areas where there are substantial inducements for product development by the private sector. Few seed companies, for example, carry out much research in plant pathology, plant physiology, genetics, crop management systems, or farm management. But since output of the public-sector research is a public good, it is available to large and small input suppliers alike. Because of the difficulty of patenting hybrids by public research institutions, small seed companies have been able to exist along with large firms. Thus, it has been generally in the best interest of society to support public investments in these types of research activities, since the social benefits would outweigh the costs incurred from increased concentration in the industry. A recent decision by the U.S. Supreme Court related to patentability of biological research requires careful reexamination of current policies of the public food and agricultural research agencies.

Direct or Checkoff Funds

In producer checkoff funding, several private firms or commodity groups pursue their best interests by collectively supporting public research activities. Contributors t. research probably have less control over the specific projects to be funded than would occur with an industrial firm. But the usual process is for the recipient public research agency to issue a portfolio of potential research projects for which the funds could be used. Then a governing board (often labeled a specific commodity research promotion board) selects from among the portfolio those projects that best coincide with its constituency's interest within available funds. The public research administrator then "awards" the funds to those projects and scientists proposing the specific R&D activities.

Thus, there is a tendency to focus the research toward short-term, applied R&D activities that hold promise for benefiting the clientele providing the funds. Heavy reliance on this type of funding source for public research support would bias the direction of the research toward those techniques most beneficial to the group providing the funds.

Measuring Returns to Research Investment

Most evaluations of food and agricultural research indicate a favorable internal rate of return.[4] This rate can be defined as that discount rate that equates the present value of the expected cash outflows (costs) with the present value of the inflows (benefits).

The acceptance criterion for a research proposal is based on the relationship of the internal rate of return to a required rate of return. For a private firm, the required rate might be the cost of capital, while for the public sector, it might be some long-term interest or social discount rate. If the internal rate of return is higher than the required rate, the investment should be undertaken.

Several studies that have empirically estimated rates of return on agricultural research investment are summarized in table 6. For aggregate investment, rate-of-return estimates are predominately in the range of 30 to 40 percent. However, the lowest estimate for this category is 23.5 percent compared to the highest estimate of 100 percent. Some of the returns on individual commodities are outside this latter range. The most obvious conclusion from these consistently high rates of return is that agricultural research is very profitable.

Table 6.—Empirical Rate of Return Estimates for Agricultural Research investment

Study	Commodity	Time period	Internal rate of return (percent)
index number approach			
Griliches (1956)	Hybrid corn	1940-55	35-40
Griliches (1958)	Hybrid sorghum	1940-57	20
Peterson (1967)	Poultry	1915-60	21-25
Schmitz and Seckler (1970)	Tomato harvester	1958-67	37-46
			16-29[a]
Peterson and Fitzharris (1975)	Aggregate	1937-42	50
		1947-57	51
		1957-62	49
		1967-72	34
Regression analysis approach			
Griliches (1964)	Aggregate	1949-59	35-40
Peterson (1966)	Poultry	1915-60	21
Evenson (1968)	Aggregate	1949-59	47
Lu and Cline (1977)	Aggregate	1938-48	30.5
		1949-59	27.5
		1959-69	25.5
		1969-72	23.5
Knutson (1977)	Aggregate	1939-48	49.7
		1949-58	47.4
		1959-68	39.4
		1969-72	35.5
White, Havlicek and Otto (1978)	Aggregate	1929-41	36.5[b]
		1942-57	32.2[b]
		1958-77	27.8[b]
Davis (1979)	Aggregate	1949	100[c]
		1954	79[c]
		1959	66[c]
		1964	37[c]
		1969	37[c]
		1974	37[c]
Bredahl and Peterson (1976)	Cash grains	1969	36
	Poultry	1969	37
	Dairy	1969	46
	Livestock	1969	47
Norton (1980)	Cash grains	1974	35[d]
	Poultry	1974	46[d]
	Dairy	1974	51[d]
	Livestock	1974	88[d]

[a]Estimates account for compensation of displaced workers.
[b]The estimates were reduced by one-third to correct for the omission of Private research
[c]Estimates are based on cross section using real output and deflated research Estimates are high because extension is omitted and a small adjustment for private research is used. If adjustments are made these rates would be around 20 percent for 1964-79
[d]These estimates correspond to the mean lags used by Bredahl and Peterson (1976).

SOURCE Fred C White, B R Eddleman, and J. C. Purcell, "Nature and Flow of Benefits From Agriculture.Food Research," OTA background paper, 1980.

4 Havlicek and Otto note that research concerned with measuring impacts of agricultural research has focused on either total or production-oriented research and the impact this research has on productivity, output, or value at the producer level. However, effects of all agricultural research are not always to increase productivity, output, or value, nor is the output of all agricultural research measurable and perceived in the marketplace. In addition, these studies for the most part have not taken into account such externalities as environmental and social impacts. Alternative measures are discussed in the Havlicek and Otto background paper, 1980.

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Four of the studies show that returns to agricultural research were higher in the early part of the century and have recently declined slightly. A likely explanation is that now there are fewer opportunities to substitute new technology for labor. However, the rates of return in the most recent periods are still quite high. Davis (1979) noted that since 1964 the marginal internal rate of return has remained surprisingly constant and may have stopped declining.

The high rate of returns are evidence of a resource allocation problem. Economic efficiency calls for investment funds to be allocated in such a manner that the marginal returns in all categories are the same. The high rate of return on agricultural research indicates underinvestment by the public sector. In other words, additional resources should be allocated to agricultural research in order to bring its rate of return in line with the returns from other public investments. Why has there been an apparent underinvestment in agricultural research?

At the symposium on Methodology for Evaluation of Agricultural Research held in Minneapolis, Minn., in May 1980, a government official said, "It is clear that the role of the Federal Government is not to turn a profit . . ." (Franz). While this statement may represent the sentiments of many legislators and other government officials as related to the high returns on agricultural research investment, it warrants further elaboration and interpretation. Economic growth traditionally has been fostered in this country as a means to progress. Furthermore, economic efficiency is a means to achieve economic growth, and it would be improper to ignore the rate of return of estimates as an indicator of economic efficiency. Complications arise, however, as society attempts to achieve a variety of goals.

The social optimum actually may involve a tradeoff between goals. For example, the public sector might choose to limit expenditures in a particular category below the level called for by economic efficiency if such expenditures would affect adversely the distribution of income. This particular relationship is commonly referred to as the tradeoff between efficiency and equity.

Agricultural research expenditures over the last half century may have been limited by policy makers' perception of excess capacity in agriculture. Congress continually battled with the problem of depressed farm prices caused by excess production at prices considered to be socially acceptable. Policy makers were probably aware of the dilemma that if research investment increased supplies, costs of maintaining farm prices would increase. The problem facing policymakers in this area revolves around what will happen to agricultural supplies and farm prices in the future. If excess capacity is projected to continue into the next century, policymakers will limit agricultural research expenditures. However, if increased agricultural productivity will be needed to furnish adequate supplies for domestic consumers and foreign trade, a greater level of research investment would be warranted.

Policymakers may limit agricultural research expenditures because of the uncertainties about future benefits from agricultural research. The estimated rates of return are based on historical relationships that may not hold in the future. Even though expected returns may be high, policy makers may perceive a wide standard deviation around the expected returns, believing that they are not measured precisely. Although there is some controversy in this area, there appears to be widespread support for the proposition that the public sector should invest on the basis of emphasis on expected returns rather than on risk factors (White, Eddleman, Purcell, 1980). However, policymakers may contend that expected returns are not measured accurately enough to guide decisions on the optimal level of public investment in food and agricultural research.

QUALITATIVE MEASURES

Quality is an important aspect of all research and is a well-accepted concept. While difficult to measure from a quantitative standpoint, there are certain aspects of quality that most scientists would agree are essential to reach a minimum acceptable level. These include dealing with adequate numbers of samples, reproducing data, recording data so that it can be understood and evaluated by others, organizing and conducting research so that it is amenable to statistical analyses, etc. Difficulties arise when an attempt is made to evaluate the relative degree or level of quality among a group of scientists or among a series of researchers within or between disciplines or areas of research. Difficulty also arises in evaluating the relative contribution a piece of research makes to the advancement of the field of study.

Pound Report

Quality is addressed because it became, perhaps unintentionally, one of the major messages to come out of the so-called Pound Report of 1972 ("Report of the Committee on Research Advisory to the U.S. Department of Agriculture," NAS). This report has been referred to by the Office of Management and Budget (OMB) and others as an authoritative source on the measurement of the quality of agricultural research and, thus, a rationale for nonsupport of agricultural research. The committee, which was composed primarily of bench scientists closely oriented more toward basic aspects of agricultural research, took as its major guideline the question: "Is the quality of science being used in solution of agricultural problems consistent with the public needs and scientific possibilities?" (p. 10).

In its general summary about the quality of the research effort, it concluded that ". . . much of agricultural research is outmoded, pedestrian, and inefficient" (p. 11) and that ". . . far too much of the research is of low scientific quality. . . ." (p. 12). Under the question: "Does the research by agricultural scientists reflect the highest standards of the community?" it concluded that:

> Most of the specific disciplinary research studies made by the Committee and its panels reveal a shocking amount of low quality research in agriculture. Admittedly, quality is a judgment factor but the regularity with which the Committee came up with judgments of low quality, including both SAES and USDA research, is significant and appalling (p. 70),

This criticism was emphasized in two articles in Science magazine (Jan. 5, 1973; Apr. 27, 1973). The articles were given wide publicity and used against agricultural research by OMB and other groups.

The Pound report did not give a precise definition of "agricultural science" or "quality;" nevertheless judgments were made that involved both. The group mainly asked certain peer group panels to rate some specific research project summaries contained in USDA's Current Research Information System in certain areas of work, such as forest insect research, reproductive physiology, and molecular biology, that had been written for general descriptive purposes (p. 70). Additionally, the reactions of some other scientists to agricultural research quality were collected in an informal manner. Therefore, the adequacy of this evaluation itself is in question.

Other Reports

Other assessments of published output of scientists have been used to evaluate certain aspects of agricultural research, most notably productivity (e.g., Salisbury). The use of this technique or variations of it for determining quality is a more recent innovation. Two examples are cited.

Shaw Report

B. T. Shaw, former administrator of ARS, analyzed the use of publication as a criterion for evaluating scientists and the quality of research, Three evaluation approaches were tried in the analysis:

1. a peer group of scientists reading the publication,
2. number of publications, and
3. publication outlet.

The first approach was found to be the only satisfactory method. However, it would not have been feasible for the Pound committee, because it would have required reading some 3,500 ARS publications.

As a compromise, each scientist for the Shaw report was asked to rank his own publication by assigning it to one of the following categories, in decreasing order of scoring:

1. Original research in terms of its impact on science, agriculture, and general welfare:
   —very great (100 to 81),
   —great (80 to 61), and
   —moderate to limited (60 to 51).
2. Reviews:
   –for scientists (50 to 41), and
   –for laymen (40 to 31).

Division directors then were asked to rank the 118 papers: 10 ranked 95 or higher, and 105 ranked 55 or higher. This rating system gives greater weight to original research than to reviews and tries to emphasize impact of research.

Evenson and Wright

Two economists, Evenson and Wright, attempted a somewhat different approach as a special project for this (the OTA) study. They evaluated citations of: 1) publications in peer-reviewed journals and z) patents. Examples of patents were drawn from the field of post-harvest technology and, therefore, may not be applicable to production technology.

In the case of publication citations, two comparisons were made: between the State and USDA, and changes over time between 1966 and 1978. In both cases, no significant differences were found. One USDA center having the lowest journal citation score had the strongest performance in patenting. When expenditures per scientist man-year (SMY) were factored in as a measure of support per scientist in terms of equipment, assistants, etc., it did not affect publications per SMY but it did positively affect citations per publication and total citations per SMY.

In the case of patents, the study was limited to USDA (the four regional utilization laboratories) with a sample comparison with private U.S. companies and foreign firms. Comparisons then were made of citations in subsequent patents. The three groups were shown to be roughly comparable for food, but private firms rated higher on textile patents.

General Comments

The number of publications or patents and the number of citations do not give a quantitative indication of quality. Quality is not necessarily a function of numbers of publications or patents. NAS considers peer review probably the best method of estimating quality. Even here, attempting to use the same criteria or the same scientists across disciplines is hazardous. Estimating quality in agricultural research, which most frequently is mission oriented, ranging from the most basic to the most applied, requires great care. The same criteria or the same scientists cannot be used for evaluating the basic research as are used for evaluating the applied.

Consider the work of Dr. Norman Borlaug. Borlaug did not break new paths in fundamental science or in the basic theory of plant breeding. Rather, he applied well-known techniques of plant breeding, along with a few innovations in testing, to create a line of improved wheat varieties that were used to increase food production rapidly in many of the world's developing countries. Also, he did not publish much before receiving his Nobel prize, and those papers he did write were not classified as basic research.

It is possible for peers to evaluate agricultural research quality, even though such evaluations are largely subjective. Peer review is review of a scientist's research only by researchers within the same general area, discipline or mission. For example, in the continuum of basic to applied research, peers of scientists working in basic research can effectively review quality of scientists working in similar basic areas of research. Scientists working in applied areas can evaluate quality of other scientists working on similar applied problems. However, it is generally meaningless for a group of scientists working in basic research to evaluate the quality of those working in the applied area and vice versa.

While quality is important, it can be measured only in a very narrow sense. To measure the value of food and agricultural research to society, which is the measurement of output to input, it should be cumulatively examined across the full spectrum of activity —i.e., discipline to discipline, basic to applied. This is best done by analyzing what has happened to the industry. And by any measurement, U.S. agriculture has been extremely productive.

PRINCIPAL **FINDINGS**

- USDA research expenditures are the lowest total Federal expenditures by a major Federal research agency for R&D. In 1978 USDA's share of Federal expenditures for R&D was 1.5 percent of total expenditures compared to DOD—45 percent, DOE—16 percent, and HEW—12 percent,

- Increase in purchasing power of total SAES and USDA agricultural research expenditures increased only 23 percent in constant dollars from 1966 to 1979,

- Constant dollar agricultural research expenditures of USDA for in-house research increased only 1 percent between 1966 and 1979, while those in the SAES increased 40 percent.

- State appropriations are the major source of research funding at the SAES, and in constant dollars increased 57 percent from 1966 to 1979. Federal Hatch funds account for 20 percent of SAES funding, and in constant terms have increased on the average 1.5 percent a year from 1966 to 1979, or 20 percent for this time period.

- Private research funds for agricultural research at SAES are small relative to State appropriations and Federal formula funds. They have steadily increased since 1966—63 percent in constant dollars—and are becoming an important source of agricultural research funds.

- Private industry agricultural research is a major contributor to total agricultural research in the United States. It is estimated that total expenditures by private enterprise are about three-quarters of the expenditures of the State and Federal governments combined.

- The justification of public funding of food and agricultural research is based on benefits well in excess of costs. Issues of equity, because of the interstate flow of food and related commodities and the spillover effect of research from one geographic region to another, are also cited. Producers benefit from expanding demand and from reduced costs. The distribution of consuming population among States, however, is related to the distribution of agricultural production only to a very limited degree, From the equity consideration of the geographic distribution of costs associated with research and the benefits flowing from this research, substantial Federal funding of food and agricultural research is considered the most equitable. Paradoxically, Federal funding relative to State funding of research has decreased as the interstate flow of commodities has increased. Therefore, taxpayers in food-surplus States are subsidizing consumers in food-deficit States, and the degree of subsidization is increasing steadily.

. Evaluation of the quality of research, both basic and applied, although difficult, is essential. The peer-review method appears to be the best method available, but requires that the peers be truly peers, selected from the same basic disciplines or mission area being evaluated.

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