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Economic Returns to Public Agricultural Research

Keith O. Fuglie and Paul W. Heisey

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Over the last several decades, the U.S. agricultural sector has sustained impressive productivity growth. The Nation's agricultural research system, including Federal-State public research as well as private-sector research, has been a key driver of this growth. Economic analysis finds strong and consistent evidence that investment in agricultural research has yielded high returns per dollar spent. These returns include benefits not only to the farm sector but also to the food industry and consumers in the form of more abundant commodities at lower prices. While studies using different methods and coverage give a range of estimates of returns to agricultural research, there is a consensus that the payoff from the government's investment in agricultural research has been high.

Agricultural Productivity Growth Is a Driving Force in U.S. Agriculture

Whether measured as crop yield per acre, milk and meat yield per animal, or average output per farm worker, the productivity of U.S. agriculture is among the highest in the world. The reasons for gains in productivity are many. For example, corn yields have increased through greater use of agricultural inputs, such as more fertilizers and machinery per acre of land. The development of new technology, however, also has helped boost yields. New technologies not only made inputs more effective but allowed them to be combined in new and better ways. For example, precision agriculture allows farmers to target fertilizer use more judiciously, raising crop yields and reducing costs. ERS has developed statistical series to distinguish the contribution of changes in input use from that of other factors affecting the growth of the agricultural sector. In particular, ERS has developed an index measure of Total Factor Productivity (TFP) to distinguish the effects of innovation and related factors on the growth of agricultural output.[1] In the long run, growth in TFP is the primary source of new wealth creation in the economy. Therefore, trends in agricultural TFP may provide an indication of the longrun performance of the sector.

[1]For more information on trends in agricultural productivity growth, see the ERS Economic Brief *Productivity Growth in U.S. Agriculture*.

For the period 1948-2004, the index value for output reached 266 in 2004, compared with the base year, 1948, meaning that total agricultural production in 2004 was 2.66 times higher than it was in 1948 (fig. 1). Over the same period, aggregate use of inputs (land, labor, capital, and intermediate inputs) in agriculture actually decreased slightly. Although the use of some inputs, such as fertilizer and machinery, increased, these increases were offset by reductions in cropland and, especially, the amount of labor employed in agriculture. Overall, the amount of crop and livestock output produced per unit of (aggregate) input, or the change in TFP, increased dramatically. From 1948 to 2004, agricultural productivity growth was strong in each decade, allowing output to grow with little or no increase in inputs throughout the period.

Today's Investment in Research Drives Tomorrow's Growth in Productivity

Analysts have found a strong link between investments in research and innovation and agricultural productivity growth. However, there is a long lead time between the research stage of a new technology and the point at which that technology is adopted and begins to affect productivity. Therefore, tracking research investments in food and agriculture is a good indicator of the likely future trends in agricultural productivity growth. In the United States, both the public sector (Federal and State governments) and the private sector invest heavily in agricultural research. From 1971 to the late 1990s, public and private agricultural research spending combined rose from just over 3 percent to about 7 percent of agricultural GDP (analysts have not been able to systematically track private-sector investments in food and agricultural research since 1998 due to unavailability of comparable data)(fig. 2). In constant 2001 dollars, annual spending on food and agricultural research in the United States increased from about $4.6 billion to $8.8 billion between 1970 and the late 1990s, with the private sector accounting for most of this growth. Public spending for agricultural research was mostly flat (after adjusting for inflation) between 1978 and 1998 but showed some renewed growth during 1998-2004. Note that public spending on agricultural research includes not only support for productivity-oriented research but also research on natural resources, food nutrition and safety, rural development, and economics. About 60 percent of public agricultural research is for enhancing productivity and the rest is for other objectives or fields of study. About 70 percent of private research in the late 1990s was oriented to farm production and about 30 percent went to food manufacturing.

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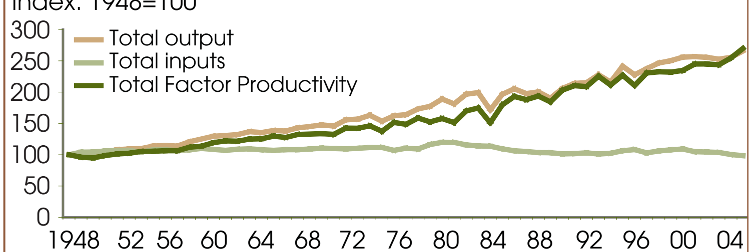
Figure 1

Changes in U.S. agricultural output, inputs, and Total Factor Productivity since 1948



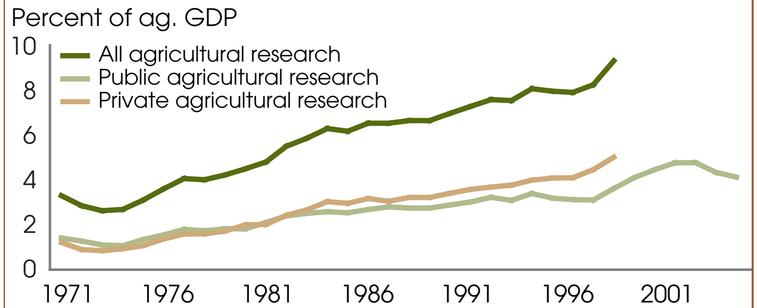
Source: USDA/ERS.

Economic Studies Find High Social Returns to Investments in Agricultural Research

Economic assessments of payoffs from public investments in agricultural research have attempted to determine the "social rate of return" to this expenditure (see box, "How Economists Evaluate Returns to Agricultural Research"). This is reported as a percent return on each dollar spent on research. The return is "social" because it includes all of the economywide benefits from higher productivity. These returns benefit not only farmers but also the food industry and consumers, who gain from more abundant and lower cost commodities. As a benchmark, social returns to public expenditures are often compared with the return to U.S. Treasury Bonds as a measure of the opportunity cost of public funds. Historically, the real return on U.S. government securities (the real return equals the nominal return minus the inflation rate) has been around 3-4 percent per year.

Figure 2

Public and private food and agricultural research spending relative to agricultural GDP



Source: USDA, ERS (public and private agricultural research expenditures) and Economic Report of the President (agricultural GDP—calculated as a 3-year moving average).

Against this benchmark, economic studies find that public expenditures on agricultural research have yielded real returns several magnitudes higher. Some of these studies have estimated returns to research on particular commodities or in particular States, but several have assessed returns to investment in the Federal-State public agricultural research system as a whole, for various periods of the 20th century. For 35 studies published over 1965-2005 that were reviewed by Professors Wallace Huffman (Iowa State University) and Robert Evenson (Yale University), the median estimate of the social rate of return was 45 percent per year (table 1). As a rough approximation, this implies that each dollar spent on agricultural research returned about $10 worth of benefits to the economy.[2] Although these studies have produced a range of estimates of the rate of return to agricultural research (estimates are sensitive to methods and assumptions), they all agree that the return to public agricultural research has been significantly higher than the benchmark return from government securities.

[2] An internal rate of return can be converted (approximately) into a benefit-cost ratio by dividing the social rate of return by the opportunity cost of capital. If we allow 4 percent (the longrun real yield of U.S. Government securities) to represent the cost of social capital, then a rate of return to research of 40 percent would imply a benefit-cost ratio of about 10 to 1.

ERS analyzed findings from 27 studies that assessed the rate of return to public agricultural research in the United States over various periods of the 20th century. Estimated rates of return varied depending on study methodology and coverage, but the major share ranged from 20 to 60 percent (fig. 3). Specific results from several of these studies (those published in peer-reviewed journals or as Ph.D. theses) are reported in table 2. Most of the studies were published in the 1970s through the 1990s, which suggests the estimates are becoming somewhat dated. We have found only one study estimating returns to agricultural research published since 2000.

Several other conclusions can be drawn from the literature on returns to agricultural research:

- *Returns to research have been high for most crop and livestock commodities.*
  Economic studies that have estimated returns to research on particular crop or livestock commodities have usually found evidence of high returns, although returns do vary by commodity and over time. However, there is little clear evidence that research on certain commodities has given consistently higher returns than research on other commodities.

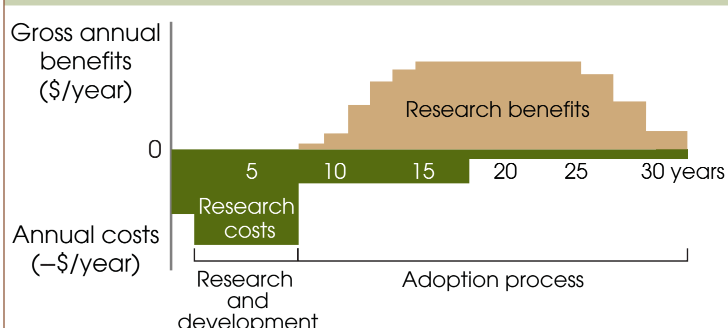
How Economists Evaluate Returns to Agricultural Research

Economic evaluations of agricultural research are based on comparisons between (i) public and private investments in agricultural knowledge creation and dissemination, and (ii) long-term changes in agricultural productivity. Conceptualization of this process is as follows:

- Expenditures on agricultural research generate new knowledge that eventually leads to improved technology that is adopted by farmers.
- Technology adoption increases average productivity (the output of crop and livestock commodities per unit of land, labor, capital, and intermediate inputs employed in production).
- Higher productivity of agricultural resources leads to lower costs, higher production, and/or exit of some resources (such as labor) from the agricultural sector.
- Given physiological limits to per capita demand for food, higher agricultural production leads to lower commodity prices, passing some of the technology-induced cost reductions on to the food industry and consumers. Thus, benefits of productivity-enhancing agricultural research are shared between the farm and nonfarm sectors of the economy.

The accompanying figure illustrates the typical time pattern of development, adoption, and eventual obsolescence of agricultural technology. As shown, a public (or private) institution invests in the development of a new technology (such as a new crop variety with disease resistance) and spends several years working on that effort ("research costs" in the figure). After about 7 years, the technology is successfully developed and farmers begin to adopt it. Costs are still incurred in extension efforts, and benefits grow as more farmers adopt the technology and reap higher yields or lower production costs. In the figure, it takes about 8 years (from year 7 until year 15) for the technology to be fully adopted and benefits maximized thereafter. But after some time, the technology eventually goes out of use, either because something better replaces it or because it loses its effectiveness (due to buildup of resistance in the pathogen, for example). An economic evaluation of the research endeavor weighs the size of the research and extension costs against the economic benefits from technology adoption, discounting the benefit and cost streams to measure them in terms of their "present value."

Flows of research costs and benefits over time



Source: Alston, Norton, and Pardey, 1995.

There are two main approaches used to estimate economic returns to agricultural research:

Statistical analysis relating past expenditures on research to current changes in productivity. These models try to establish a statistical correlation between when, where, and what research was done and productivity gains in agriculture. The analysis is usually done at a fairly aggregate level and covers a long period of time. For example, a study may look at the annual pattern of changes in agricultural productivity at the national or State level over several decades and then relate this in a regression model to investments in public and private agricultural research and extension over a similar period (with research investments beginning earlier than productivity changes to account for the lag time between research and technology adoption). These studies also examine effects of other factors that may contribute to productivity growth, like investments in rural education, extension, and infrastructure. If regression analysis finds positive and significant correlations between research expenditures (appropriately lagged) and productivity changes, then this is taken as evidence of a causal relationship. An estimate of the rate of return to research is derived from the regression coefficients.

Project evaluation methods tracing the development and dissemination of innovations. An early example of this approach was a study by Zvi Griliches (Dept. of Econ., University of Chicago) in the 1950s on the returns to research on hybrid maize. He estimated the benefits of hybrid maize by measuring the economic value of higher maize yield made possible from this innovation. On the cost side, he estimated the cost of research and extension (by both the public and private sectors) beginning with the work of George Schull of the Carnegie Institution and Donald Jones of the Connecticut Agricultural Experiment Station, who developed the theory of hybrid vigor and invented the double-cross method of hybrid seed production.

The case study method provides a clearer cause-and-effect relationship between agricultural research and productivity growth than the regression method. But the case study method has largely been limited to analysis of research "success stories." Regression methods, on the other hand, assess the system at a more aggregate level and take into account expenditures on research that may or may not lead to successes and, therefore, tend to give a more balanced measure of average returns to a research system. Both approaches involve estimating relationships between the size of investment in research and the economic value of increased productivity, taking into account the appropriate time dimension between when research is done and when economic benefits are realized, such as the case depicted in the figure. Estimates of social returns to research may be overstated if undesirable outputs (e.g., environmental degradation) are not taken into account. Similarly, social returns may be understated if new technology reduces undesirable outputs.

Some of the most challenging aspects of these models are:

- ***Lags:*** Identifying the appropriate lag relationship between when research is done and when productivity growth occurs.

- ***Spillovers:*** Accounting for knowledge or research "spillovers" across geographic space. Spillovers occur when research done in one State, region, or country contributes to new knowledge or technology that is used in another geographic area.

- ***Attribution:*** Accounting for the many elements that come together to contribute to the development and application of new technology to agriculture. In addition to publicly funded agricultural research, contributions include those made by basic sciences, innovations from the private sector, farmer education, the training role of extension services, and improvements to rural infrastructure. These institutional sources are often complementary, and failure to account for the contribution of one source may overattribute observed gains in productivity to another source. Including all these sources in a model may give an indication of the relative importance of each source (and the relative rate of return to each). Some studies go even further to try to distinguish returns to agricultural research done by Federal or State institutions, or even by different Federal funding instruments (e.g., formula versus competitive grants). But putting finer and finer distinctions among sources of innovation and types of research expenditure places a heavy burden on the data.

Table 1–Summary estimates of the rate of return to U.S. agricultural research

Item	Studies, 1965-2005	Mean estimate	Median estimate
Social rate of returns to public agricultural research	35	53	45
Social rate of returns to private agricultural research	4	45	45

Source: USDA, ERS, using data from Huffman and Evenson, 2006, and Fuglie et al.,1996.

- *There appear to be significant social returns to private agricultural research.*

Manufacturing industries, especially for chemical, machinery, pharmaceuticals, and food and feed processing (and, more recently, for biotechnology), are significant sources of new technology for agriculture. The private sector earns a return from its investment in agricultural research in the profit it makes on sales of improved chemicals, machines, feeds, breeds, and seeds to farmers. If the private sector could capture all of the benefits of its technology through the price it charges for its products, then private research would not register as a source of improvement in farm productivity (the value of higher output would be offset by the higher cost of inputs). Only a few studies have assessed social returns to private agricultural research, and findings suggest that private research does contribute significantly to measured productivity growth in agriculture (table 1), implying that the private sector is able to capture only a share of the productivity benefits from its technology.

- *Agricultural research generates long-term benefits.*

That an investment in research entails a long lag time before it produces tangible economic impact is well understood. It is also clear that the lag is longer for more basic research than for more applied research, and that a sizeable share of research undertaken may never be applied to technology development that is adopted by farmers. Economists have used regression models to try to determine the average lag of agricultural research undertaken by the public sector in the United States and to determine how long this research continues to contribute to productivity growth until it becomes obsolete. As more data have been accumulated on agricultural research and growth, it has become possible to estimate more sophisticated models on the statistical relationship between these variables. Current research on this topic suggests that, on average, public agricultural research undertaken today will begin to noticeably influence agricultural productivity in as little as 2 years and that its impact could be felt for as long as 30 years.

- *Agricultural knowledge or research “spillovers” across State and national boundaries are significant.*

Although much research in agriculture is oriented toward the ecological conditions of a particular State or region, there is strong evidence (from both statistical models and observation of trade in agricultural inputs that embody new technology) that agricultural research done in one location affects productivity in other regions or even other countries. Spillovers from livestock research are generally greater than spillovers from crop research because livestock production is less constrained by agro-ecological factors like soils and climate.

Table 2—Estimates of the rate of return to Federal-State investment in agricultural research

Studies on the aggregate crop-animal sector

Study	Authors	Pub. year	Publication	Period	Coverage	ROR estimate Mid	Low	High
1	Huffman & Evenson	2006	Am J Ag Econ	1970-1999	Crops & animals	56	49	62
2	Gopinath & Roe	2000	Econ Innov & Tech	1960-1991	Crops & animals	37		
3	Makki et al.	1999	J Policy Modeling	1930-1990	Crops & animals	27		
4	White	1995	J Ag Appl Econ	1950-1991	Crops & animals	40		
5	Chavas & Cox	1992	Am J Ag Econ	1950-1982	Crops & animals	28		
6	Norton & Ortiz	1992	J Production Agric	1987, state-level comp.	Crops & animals	58		
7	Yee	1992	J Ag Econ Res	1931-1985	Crops & animals	54	49	58
8	Braha & Tweeten	1986	Tech. Bull., Ok SU	1959-1982	Crops & animals	47		
9	Lyu, White, Liu	1984	S J Ag Econ	1949-1981	Crops & animals	66		
10	White & Havlicek	1982	Am J Ag Econ	1943-1977	Crops & animals	22	7	36
11	Davis	1979	PhD thesis, UMN	1949-1959	Crops & animals	83	66	100
11	Davis	1979	PhD thesis, UMN	1964-1974	Crops & animals	37		
12	Knutson & Tweeten	1979	Am J Ag Econ	1949-1972	Crops & animals	38	28	47
13	Lu et al.	1979	Tech. Bull., ERS	1939-1972	Crops & animals	27	23	30
14	Bredahl & Peterson	1976	Am J Ag Econ	1937-1942	Crops & animals	56		
14	Bredahl & Peterson	1976	Am J Ag Econ	1947-1957	Crops & animals	51		
14	Bredahl & Peterson	1976	Am J Ag Econ	1957-1962	Crops & animals	49		
14	Bredahl & Peterson	1976	Am J Ag Econ	1967-1972	Crops & animals	34		
15	Cline	1975	PhD thesis, Ok SU	1939-1948	Crops & animals	46	41	50
16	Evenson	1968	PhD thesis, U Chic	1949-1959	Crops & animals	47		
17	Peterson	1967	J Farm Econ	1915-1960	Crops & animals	23	21	25
18	Griliches	1964	Amer Econ Rev	1949-1959	Crops & animals	33	25	40

Studies on components of the agricultural sector

Study	Authors	Pub. year	Publication	Period		ROR estimate Mid	Low	High
6	Norton & Ortiz	1992	J Production Agric	1987, state-level comp.	Beef & swine	55		
6	Norton & Ortiz	1992	J Production Agric	1987, state-level comp.	Dairy	95		
6	Norton & Ortiz	1992	J Production Agric	1987, state-level comp.	Poultry	46		
6	Norton & Ortiz	1992	J Production Agric	1987, state-level comp.	Grain crops	31		
6	Norton & Ortiz	1992	J Production Agric	1987, state-level comp.	Potatoes, cotton & tobacco	34		
6	Norton & Ortiz	1992	J Production Agric	1987, state-level comp.	Vegetables & melons	19		
6	Norton & Ortiz	1992	J Production Agric	1987, state-level comp.	Fruits & nuts	33		
23	Haygreen et al.	1986	Forest Prod J	1972-1981	Forest products	25	14	36
22	Bengston	1984	Forest Science	1975, state-level comp.	Forest products	21	19	22
19	Smith et al.	1983	J NE Ag Econ	1978, state-level comp.	Beef & swine	22		
19	Smith et al.	1983	J NE Ag Econ	1978, state-level comp.	Dairy	25		
19	Smith et al.	1983	J NE Ag Econ	1978, state-level comp.	Poultry	61		
21	Schmitz & Seckler	1970	Am J Ag Econ	1958-1969	Tomato harvester	42	37	46
17	Peterson	1967	J Farm Econ	1915-1960	Poultry	23	21	25
20	Griliches	1958	J. Poli. Econ	1940-1955	Corn	38	35	40
20	Griliches	1958	J. Poli. Econ	1940-1957	Sorghum	20		

ROR = Rate of return. Most studies assessed productivity change over a period of years. "State-level comp." refers to studies that compared productivity among States at a point in time against past research expenditures in those States. Contact the authors for a complete set of references.
Source: USDA, ERS, using data from Huffman and Evenson, 2006, and Fuglie et al.,1996.

- ***There are conjectures but little empirical evidence that returns to agricultural research have fallen over time.***

  Over time, it may become increasingly difficult for scientists and engineers to find new ways of raising crop yield or reducing the need for farm labor. In addition, as agricultural productivity reaches increasingly high levels, it is probably necessary to devote more resources to simply maintaining these levels rather than achieving even greater productivity. The need for more maintenance research does not imply that returns to research would diminish (since preventing productivity from falling has economic value) but it would imply that more research dollars would be required to prevent that rate of productivity growth from falling. So far, economic studies have not found any clear indication that the long-term growth rate in agricultural productivity has declined.

- ***There has been little empirical work assessing returns to agricultural research on nonmarket objectives (natural resource quality, food safety, economics, and policy).***

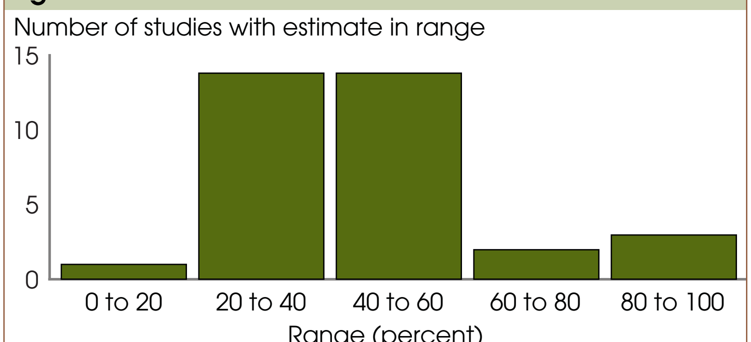
  The agricultural research system devotes considerable resources to research on natural resources, food nutrition and safety, economics and statistics, and other objectives not directly related to raising farm productivity. While economic studies have documented specific impacts of some of this research, these nonmarket outcomes have not been incorporated into estimates of returns to research.

Long-Term Prospects for U.S. Agricultural Productivity Growth

One key factor that will shape future growth in U.S. agricultural productivity is the Nation's investment in agricultural research, both in amount and in how well this research investment is used. The U.S. agricultural research system consists of Federal, State, and private-sector elements. Policies that shape this system include not only government spending for agricultural research but also policies that encourage private-sector research and farm adoption of new technology. A measure of the effectiveness of these policies is the level of public and private research expenditures relative to agricultural Gross Domestic Product (GDP). Agricultural GDP measures the value added by the agricultural sector. Combined public and private spending on agricultural research as a share of agricultural GDP more than doubled between 1970 and 1998 to just over 7 percent (see fig. 2). Comparable data for private-sector research are not available for the years since 1998, but public spending on agricultural research as a percentage of agricultural GDP continued to grow until 2002 and then fell in 2003 and 2004. So long as public and private investment in agricultural research continues to keep pace with or grow faster than agricultural GDP, and so long as this investment continues to earn the high social rates of return as in the past, prospects for the agricultural sector to maintain productivity growth are favorable.

Figure 3

Range of estimates of the rate of return to public agricultural research in the United States



Source: USDA, ERS, using data from Huffman and Evenson, 2006.

This brief is drawn from . . .

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