Economic Returns to Public Agricultural Research

A frequently used measure of research effectiveness is the rate of return earned by research investments. Many studies of the social rate of return to public agricultural research have been conducted. These studies have assessed both aggregate investments in agricultural research and various components of the agricultural system, considered different periods, and used different methodological approaches. These studies have, for the most part, found high social rates of return for most categories of agricultural research.

Conceptual Foundation for Measuring the Social Rate of Return to Research

The conceptual basis for the social rate of return to aggregate public research is drawn from straightforward estimation of the internal rate of return to an investment by a firm or household. Facing an investment decision at time *t*, the firm or household could estimate the flow of benefits (net of operating costs and depreciation) it received from the investment over time (B_{t+I}, for $I = 1,...,L$ where L is the life of the investment) against the initial cost of the investment (C_t). The internal rate of return of the investment is the value of *r* which solves the equation:

$$C_t = \frac{B_{t+1}}{(1+r)} + \frac{B_{t+2}}{(1+r)^2} + \ldots + \frac{B_{t+L}}{(1+r)^L} \qquad (1)$$

For the special case where the flow of benefits is constant over time and continues indefinitely, equation 1 can be analytically solved for *r*:

$$r = \frac{B}{C_t} \qquad (2)$$

In this simple example, if a dollar invested generated an annual net flow of returns of 50 cents, the rate of return would be 50 percent. More realistic cases where returns vary over time and where the life of the investment are limited require numerical solution of equation 1.

There are many complexities in measuring the rate of return even for a standard investment by a private firm and these complexities can pose even greater problems for estimating the social rate of return to research (see box “Social versus Private Returns to Research”). The biggest difference between measuring the private rate of return to a firm and the social rate of return is that, conceptually, the social return to an investment includes not only the returns to the technology developer but also to farmers, other producers, consumers, and other members of society. The social return to a private research investment is usually higher than the private return to the firm. Inventors frequently cannot appropriate all the benefits of their inventions because “spillover” benefits accrue to other users or consumers. Empirical studies validate the finding that the social rate of return to private research exceeds the private return.[8] This finding supports the hypothesis that the private market economy underinvests in research. Because the Federal Government is concerned with all members of society, economists argue that public decisions should use the social rate of return as a guide to determine whether research funding is adequate.

The distribution of research gains among consumers, producers, and other segments of society is also important in public decisions. A high rate of return generally means, however, that the gains to winners from the new technology exceed the losses to those who may lose from the new technology. In principle then, the gainers could compensate the losers so that everyone in the economy would be better off. Whether and how such compensation occurs is up to the political system. Also, it depends, in part, on whether people have equal opportunity to take advantage of new technological opportunities.

Federally funded research organizations generally do not privately capture the returns to publicly funded research and were legally barred from doing so until 1980.[9] This feature of public research means there is not a conceptually comparable private return to public research. The beneficiaries of public agricultural research are those who use the knowledge generated in their production processes and in their decisions. These beneficiaries may be manufacturing firms that produce and sell improved inputs to farmers or that manufacture food and fiber products for consumers. New knowledge generated from research may also be used directly by farmers in their production decisions, by consumers in their consumption decisions, and by government agencies in public policy decisions. Generally, the benefits of research extend beyond the initial users. Benefits spread to other parts of the economy when the new technology results in lower production costs for farmers and, eventually, lower product prices for consumers. In this way, the benefits of, for example, a new seed variety partly accrue to the firm that produces the seed but also flow to farmers, purchasers of the farm product, and consumers.

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[8]For example, Mansfield and others (1977) estimated that the social rates of returns for manufacturing innovations were clustered around 50 percent while the private rates were around 25 percent.

[9]In fact, the economic benefits to research are highest when new technologies are priced only to cover the input cost of producing them and do not include monopoly “rents” to compensate for the inventive effort embodied in the technology.

Social versus Private Returns to Research: Issues of Measurement

The direct economic benefits of research are measured by examining how the improved technology reduces the cost of output. Reductions in the cost of output generally result in some combination of higher returns to producers, lower prices, and more consumption. Some complications that arise in estimating the social rate of return are unique to the assessment of public investment in research. Measurement issues include:

❖ ***The private rate of return does not include spillover benefits (or costs).*** In principle, the social return to a research investment includes any returns to the innovator plus returns to farmers, other producers, consumers, and other members of society. Because of spillovers, the social return to private research is usually much higher than the private firm's return.

❖ ***Some spillovers are not included in estimated social rates of return.*** Rate-of-return estimates have generally not included research benefits that spill into the United States (from other countries) or out from the United States (to other countries). Therefore, benefits of federally funded research that do not accrue to U.S. citizens are treated separately. Spillovers into and out of non-agricultural sectors also generally are not included. Failure to include these spillovers can lead to biased estimates. Failure to attribute gains to private research funding can lead to an overestimation of the returns to public research.

❖ ***Global spillovers are significant.***

❖ ***The depreciation cost associated with the stock of technical knowledge is difficult to estimate.*** Some analysts assume that knowledge does not depreciate. If research stopped and no new knowledge was uncovered, technological progress would stop but would not regress. At least for some forms of more applied agricultural technology, this assumption is not accurate; pests develop resistance to new pesticides over time and thus the value of research on pesticides depreciates over time. Without a steady stream of new research, agricultural productivity would fall rather than simply stop growing.

❖ ***Benefits from research can be realized only several years after the research is conducted.*** There are several sources of lags: (1) A particular R&D project may take several years to complete, and application of basic research results may require further applied research and development; (2) time between development and commercial production may be several years, particularly if commercialization requires Federal approval of the safety and efficacy of the technology; (3) full commercial adoption generally occurs only after a period of several years; (4) use of a technology will cease completely when a superior technology appears.

❖ ***Market prices may not be the correct measure for assessing social returns.*** Valuation of some effects of new technology, such as effects on natural resources and the environment, health, communities and families, and rural landscape, is difficult because market prices do not exist.

The methodologies generally used to estimate the social rate of return to agricultural research focus on observed changes in market behavior and market prices. Statistical approaches that analyze the production efficiency of the economy cannot capture some effects of a technology on producers and consumers. In particular, rate-of-return studies do not measure the benefits of improved consumer and governmental decisionmaking and only capture some environmental benefits or costs of new technology (see box, "Social Benefits Not Captured in Rate of Return Estimates").

New technologies may not be beneficial to all parts of the economy and society. Negative effects of the technology on the environment, natural resources, health, or community and family life may lead private firms to estimate a return to research that exceeds the social return if the offending activities are not taxed or regulated. Based on this private profit incentive, the market economy may overinvest in some types of research. Researchers currently lack the empirical basis for estimating the full social rate of return to research that accounts for all the societal effects of new technologies.

The Social Rate of Return as a Guide to Funding Decisions

Statistical estimates of historical rates of return to agricultural research can yield insights on how much resources should be allocated to research, how those resources should be allocated among research programs, and who should assume primary responsibility for funding different types of research. An important consideration in using rates of return to research in policy analysis is that they reflect returns to past research. Ideally, current research decisions should be based on the evaluation of the rate of return to projects currently being considered for funding. While eliciting unbiased evaluations is difficult, cost-benefit approaches have been developed for this purpose.

Social Benefits Not Captured in Rate-of-Return Estimates

Traditional methods for estimating returns to agricultural research were designed primarily to consider improvements in the productive efficiency of the agricultural economy. Effects of research where benefits are not well captured in traditional rate-of-return studies include:

- ***Consumer decisionmaking, family life, and community development***. Research to understand nutrition and health effects of food consumption choices is effective if it leads consumers to make food choices that help them to be healthier and to live longer. There are benefits to the economy of a healthier population, such as improved productivity while on the job or in school, reduced medical expenditures, and fewer absences from work or school. In principle, these changes could be measured. Improvements in family life and community development are less easily defined and even more difficult to value. Other evidence of effectiveness of research on these issues may provide better guidance on the adequacy and allocation of funding.

- ***Public decisionmaking***. Firmer scientific or social scientific understanding can identify problems requiring government intervention, can explain that a perceived problem is less severe than generally believed, and can be necessary to estimate the effectiveness and cost of proposed remedies. For example, research efforts directed toward understanding changes in surface and groundwater quality, food safety, global climate change, and changes in air quality are aimed at helping public decisionmakers decide what to do about these problems. Estimating benefits requires that the social outcome resulting from the actual decision be contrasted with the counterfactual outcome resulting from decisions that would have been made with mostly scientific information.

- ***Environmental technologies***. For regulated or taxed environmental consequences, traditional rate-of-return studies will capture the environmental benefits of new technology. These benefits are known because the new technology reduces the cost of compliance with the regulation or the amount of environmental tax. This reduced cost reflects increased productive efficiency. For environmental problems that are not regulated or where the regulation or tax is insufficient to reduce pollution to a socially desirable level, traditional rate-of-return studies will undervalue research on new technologies that reduce pollution.

A simple investment rule in the rate-of-return literature says that a firm should invest in a project if the rate of return exceeds the interest rate the firm must pay on borrowed funds. Modern finance theory has revealed many reasons, such as risk, why this simple rule may not apply even for the firm undertaking a standard investment. A number of additional issues arise in assessing public investments, especially for research (see box, “Using the Rate of Return to Make Research Funding Decisions”). The rate below which projects are not funded is sometimes called the hurdle rate. There is considerable disagreement concerning the appropriate hurdle rate for public investments. Based on estimates of the social discount rate or on the risk-free market rate of interest, a hurdle rate of 5 percent or less could be justified for public investments. However, the economic efficiency for agricultural research cannot be judged apart from the return to investments in other areas of the economy. While additional funds to agricultural research may yield net benefits, this would not be the most efficient use of funds if other areas of the economy were more seriously underfunded. Fox (1985) argues that the social rate of return to agricultural research should be compared with the social rather than the private rate of return to public and private investments. Using data from *Forbes* (Jan. 14, 1985) on 5-year average rates of return for 1,000 U.S. firms, Fox estimated that the social rate of return to assets ranged from 17.8 percent to 22.8 percent per year. Ruttan (1980) argued that a level of investment in agricultural research that would push rates of return to below 20 percent would be in the public interest.

Comparing the estimated rate of return to aggregate spending for agricultural research with the hurdle rate for public expenditures suggests whether too little resources are being allocated to research. If the rate of return to agricultural research exceeds the hurdle rate, then social welfare could be enhanced by devoting more resources to research but at the expense of other investment activities that yield a lower rate of return. For a predetermined budget, estimates of rates of returns to different components of the budget can be used to rank the components accordingly. If the marginal rate of return to basic research was found to be higher than applied research, for example, it would imply that efficiency could be increased by reallocating some research from applied to basic research. Less money for applied research should drive up the marginal return of remaining funds (assuming they were spent in the most productive areas), while more money for basic research would drive down its marginal rate of return. At some point the returns to each would be equal, implying a more efficient allocation of the existing budget for research.

Using the Rate of Return to Make Research Funding Decisions

The rate of return for a conventional investment would, in its simplest application, be compared against the interest rate a firm must pay on funds borrowed to pay for the investment. For several reasons, the social rate of return to research has a less direct interpretation. Issues include:

- ***Past research.*** The return to past research, as measured in most studies, applies to current decisions only if research system performance will be the same in the future. An important aspect of this is that scientific opportunity continues to expand as technology advances. Some people have argued that scientific opportunities may gradually be exhausted, but there is little evidence to support this idea.

- ***Different decision rules.*** A firm makes decisions based on the rule that the estimated rate of return for a project must exceed the borrowing rate to be economically justified. Society's decision rule is more complicated because: (1) raising tax revenues creates distortions in the economy, which are extra costs termed "deadweight losses" by economists, and (2) the appropriate "social discount rate" on which to base public decisions is not directly observable. A risk-free, real (inflation-adjusted) market rate of interest is one standard of comparison. On this basis, the appropriate rate is usually estimated to be between 3 and 5 percent. Intergenerational equity is also a component of the social discount rate, but this component is not revealed by the market rate. Conceptual problems arise if public investment decisions are based on one rate while the private sector's are made based on a different rate.

- ***Measuring the rate of return.*** Economists seek to measure the marginal rate of return to research: that is, the return on the last dollar invested or on the last project funded. Conceptually, it is assumed that research funders align projects from the highest to lowest expected rate of return funds are exhausted. More accurately, the estimated marginal rate reflects the rate research managers would earn on another dollar of funding given the constraints under which they operate. This interpretation means that it may be possible to reallocate funding, remove constraints, or reorganize the research system and do better. A low marginal rate of return, therefore, may suggest a failure of the funding system rather than a lack of scientific or technological opportunity.

- ***Uncertainty and risk.*** Uncertainty introduces special considerations. A private firm may display risk aversion and demand a risk premium to undertake uncertain investments. A full portfolio of investments in the economy effectively acts as insurance, pooling the risks of many individual projects. Thus, public sector investments generally consider only the mean return and not special considerations for high risks. A second issue associated with uncertainty, however, is option value. Recent research on firm investment behavior has emphasized that uncertainty may introduce a value to waiting, which is referred to as option value. Committing investment to uncertain research eliminates the option to use the funds in some other way. This argument has been used to explain why firms demand a hurdle rate above their cost of funds. However, research investments generally expand the realm of possibilities in the future and thus increase society's options. This suggests that a conventionally estimated rate of return understates the value of research to society because these rates do not include the value of flexibility that research provides as options for an uncertain future.

The statistical estimates of the rate of return to research also provide evidence on the size of geographic and other spillovers from research. Spillovers from research are benefits captured by someone other than those who fund it. If there are spillovers from privately funded research to society, then the social rate of return to research will exceed its expected private rate of return. Since private funding decisions are based primarily on expectations of private returns, private companies will tend to underfund research if there are large spillovers. Spillovers from research are often larger for basic, or pre-technology, research and smaller for research and development activities closer to the commercialization stage. Estimates of spillovers can also suggest Federal versus State areas of responsibility for funding research. If the benefits from research accrue primarily to a single State, then that State will have an incentive to fund it fully. On the other hand, if research conducted in a State benefits neighboring States as well, then States may underinvest in research for the same reason a private firm might. Individual States may attempt to "free-ride" on neighboring States, hoping to benefit from technologies developed in neighboring States (Khanna, Huffman, and Sandler, 1994). So, research with larger geographic or national spillovers should be more a Federal rather than State responsibility. Statistical evidence has found cross-State spillovers from agricultural research to be large, especially for livestock research (Evenson, 1989).

The benefits from agricultural research are also shared globally. Foreign consumers benefit from U.S. research that lowers the cost of exported commodities. Foreign producers may also benefit from research conducted in the United States, and vice versa, although some adaptive research is usually required to transfer agricultural technology across geographic areas. Genetic improvements in agricultural commodities are particularly dependent on international technology transfer. Kloppenburg and Kleinman (1987) provided an empirical analysis of the dependence of U.S. agriculture on foreign centers of genetic diversity. U.S. support for international agricultural research, while primarily aimed at improving agricultural productivity in developing countries, can also bring important reciprocal benefits for U.S. producers. For example, the transfer of semi-dwarf wheat and rice varieties from Mexico and Asia to the United States resulted in significant yield growth for U.S. growers (Dalrymple, 1980). Because of the global interdependence in sources of improvement for agricultural technology, Ruttan (1986) emphasized the need to strengthen the institutions supporting international agricultural research.

Empirical Estimates of the Social Rate of Return to Agricultural Research

Empirical estimates of the social rate of return to public agricultural research have used two different approaches, an economic surplus approach and a production function approach. The economic surplus approach evaluates yield or productivity changes that can be attributed to research. Productivity changes are interpreted as shifts in the supply function for an agricultural commodity. The supply shifts, in combination with econometrically estimated demand and supply elasticities, are the basis for estimating changes in consumer and producer benefits (that is, changes in consumer and producer surplus). The changes in consumer and producer benefits are compared with the cost of the research project (Norton and Davis, 1981). These studies have usually been conducted for individual innovations or individual crops where the productivity change can be more easily attributed to specific research funding. This approach requires assumptions about how research expenditures are allocated to specific productive improvements. Other assumptions are also required about when and for what period the benefits accrue. Some research investments cannot be clearly allocated. For example, allocation of basic research expenditures between specific products and innovations may be inappropriate since these expenditures may contribute to advances across, for example, multiple crops and many innovations.

The second approach relies on statistical estimation of production functions that contain R&D expenditures as an explanatory variable. These studies are usually more aggregated than the economic surplus studies. An advantage is that they do not require the judgment of the analyst to allocate research expenditures to specific innovations but rely on the statistical relationship revealed by the data. These estimates can control for other factors that may influence productivity and, thus, avoid incorrectly attributing productivity gains to R&D alone. Griliches (1963, 1964) was the first to apply this approach by including the education level of rural farm populations and public agricultural research and extension efforts as separate variables in a cross-regional agricultural production function for the United States.

Returns to Aggregate Investments in Agricultural Research and Extension

Most studies that have estimated the aggregate social rate of return to research consistently found rates of return between 40 and 60 percent (table 4). An exception is White and Havlicek (1979) who found a rate of return of 20 percent for aggregate research. Studies that have combined research and extension spending generally have found a lower rate of return to the combined total, roughly 20 to 35 percent, than when research alone was considered.

Some studies have explored the issue of whether the rate of return to agricultural research has declined over time. Some of these studies show lower rates of return for later periods than for earlier periods. Lu, Cline, and Quance (1979) estimated that the rate of return to agricultural research fell by 2 percentage points per decade between 1939 and 1972. Such a decline in the rate of return might be expected if research expenditures increased relative to the availability of technological opportunities to exploit. In other words, public funding was responding to the estimated high rates of return and moving closer to an economically optimal level of funding. Funding for agricultural research grew during 1950-1970. Such increases would be consistent with an interpretation that the funding level was gradually gaining on technological opportunity. However, public funding for agricultural research has been stagnant in real terms since the 1970's. The stagnation in funding might have driven up the rate of return, as opportunities for progress grew more rapidly than the ability to exploit these opportunities. Unfortunately, the long lag time between research expenditure and its payoff, improved productive efficiency, makes it difficult to test this hypothesis empirically.

Given the many measurement issues associated with estimates of the rate of return as discussed above, there are other possible explanations for a declining rate of return. One explanation is that the research funding system has become less effective at selecting the best projects. There may also have been biases in the measured rate of return that contribute to an apparent decline over time. If the research payoff profile has become

Table 4—Aggregate returns to public investments in agricultural research and extension

Study	Methodology	Time period	Annual rate (Percent)
Griliches, 1964	Prod. function	1949-59	35-40
Latimer, 1964	Prod. function	1949-59	[1]
Evenson, 1968	Prod. function	1949-59	47
Cline, 1975	Prod. function	1939-48	41-50
Huffman, 1976	Prod. function	1964	110
Peterson and Fitzharris, 1977	Economic surplus	1937-42	50
	"	1947-52	51
	"	1957-62	49
	"	1967-72	34
Lu, Quance, and Liu, 1978	Prod. function, R&E	1939-72	25
Knutson & Tweeten, 1979	Prod. function, R&E	1949-58	39-47
	"	1959-68	32-39
	"	1969-72	28-35
Lu, Cline, and Quance, 1979	Prod. function, R&E	1939-48	30.5
	"	1949-58	27.5
	"	1959-68	25.5
	"	1969-72	23.5
Davis, 1979	Prod. function	1949-59	66-100
	"	1964-74	37
Evenson, 1979	Prod. function	1868-1926	65
White and Havlicek, 1979	Prod. function	1929-72	20
White, Havlicek, and Otto, 1979	Prod. function	1929-41	54.7
	"	1942-57	48.3
	"	1958-77	41.7
Davis and Peterson, 1981	Prod. function	1949-74	37-100
White and Havlicek, 1982	Prod. function, R&E	1943-77	7-36
Lyu, White, and Lu, 1984	Prod. function	1949-81	66
Braha and Tweeten, 1986	Prod. function	1959-82	47
Yee, 1992	Prod. function	1931-85	49-58
Huffman and Evenson, 1989	Prod. function	1950-82	41

Note: R&E gives estimated rate of return to combined research and extension expenditures. Otherwise, estimate is for research alone.

[1]Not significant.

Sources: Economic Research Service compiled from Ruttan (1982), Echeverria (1990), Huffman and Evenson (1993).

longer over time, then some benefits of recent research may not have been allocated correctly or may not yet have been observed. There are also spillovers and complementarities of research through time. A shortfall of basic or fundamental research in one period may not affect productive efficiency in applied research for a decade or more. Much of the productivity growth of the past several decades was based on fundamental knowledge of genetics and chemical properties and improvements in machinery that originated in the 1800's. After decades of exploiting these gains in fundamental knowledge, one might expect some exhaustion of scientific opportunity. Biotechnology and computer technologies provide new basic scientific tools and insights that have not been widely exploited. The fundamental insights for these technologies date to the 1950's, but only in the past decade has there been much movement toward broad commercial application of products based on these insights. Thus, any apparent falloff in scientific potential may have been a lull rather than an inevitable trend. Still another possible explanation for a declining trend is that if, over time, more of the research was directed at nonmarket benefits such as environmental protection or human nutrition, these social returns may not have shown up in the measured rate of return.

While a declining rate of return may be due to a number of possible explanations, the evidence that the measured return has declined is weak. Evidence of a decline in the rate of return in Lu, Cline, and Quance (1979) is clearly inconsistent with some more recent studies (Yee, 1992; Huffman and Evenson, 1993; Braha and Tweeten, 1986) that include years through 1982-85. Comparing these later studies with earlier studies that include only years through 1960 (Griliches, 1964; Evenson, 1968; Cline, 1975) shows that both sets of studies obtain rates between 40 and 50 percent.

Returns to Research on Components of the Agricultural System

Besides studies of the aggregate rate of return, many studies have estimated returns to various components of the agricultural research budget. Separate estimates for different components of research provide evidence on whether the existing funds are allocated to yield the largest benefit. Redirecting funds from components with low marginal returns to those with high returns should yield a higher overall return. Research components considered in the literature include separate estimates for crops versus livestock and finer distinctions among commodities (table 5). Other researchers have compared the returns to research funding among basic (science-oriented) research, applied (technology-oriented) research, and extension and farm management research.

Most components of research spending show high rates of return, but estimates for individual components vary widely among studies. The wide variation provides little basis for strong conclusions about which components are more productive. Some studies (Bredahl and Peterson, 1976; Norton, 1981) found a higher rate of return

Table 5—Returns to components of public agricultural research

Study	Commodity	Period	Annual return (Percent)
Economic surplus approach:			
Griliches, 1958	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	1958-69	16-46
Production function approach:			
Peterson, 1967	Poultry	1915-60	21
Bredahl and Peterson, 1976	Poultry	1969	37
	Dairy	1969	43
	Livestock	1969	47
	Cash grains	1969	36
Evenson and Welch, 1979	Crops	1964	55
	Livestock	1964	55-60
Evenson, 1979	Technology-oriented	1927-50	95
	Science-oriented	1927-50	110
	Science-oriented	1948-71	45
	Technology-oriented	1948-71	93-130
	Farm mgmt. and ext.	1948-71	110
Norton, 1981	Cash grains	1969	31-57
	Dairy	1969	27-50
	Poultry	1969	30-56
	Livestock	1969	56-111
	Cash grains	1974	44-85
	Dairy	1974	33-62
	Livestock	1974	66-132
Sundquist, Cheng, and Norton, 1981	Maize	1977	115
	Wheat	1977	97
	Soybean	1977	118
Smith, Norton, and Havlicek, 1983	Livestock	1978	22
	Dairy	1978	25
	Poultry	1978	61
Huffman and Evenson, 1993	Crops	1950-82	47
	Livestock	1950-82	<0
	Science-oriented	1950-82	74

Sources: Economic Research Service compiled from Ruttan (1982), Echeverria (1990), and Huffman and Evenson (1993).

for livestock research than for cash grains research, while Huffman and Evenson (1993) found the opposite. There is, however, some consistency in studies that found a higher rate of return to science-oriented (basic) research than for applied research.

The evidence on returns to extension is extremely varied (table 6). Some studies on aggregate research found a higher return when research spending was considered separately than when research and extension expenditures were combined, suggesting a lower return to extension (table 4). This evidence and the recent work of Huffman and Evenson (1993) suggest a rate of return to extension of roughly 20 percent, lower than for categories of research. However, another set of studies including work by Huffman (1976) and Evenson (1979) found rates of return to extension between 82 and 110 percent. While Yee (1992) did not publish a rate of return to extension, his estimated parameters for extension similarly show a rate of return about 100 percent. Evenson (1979) also found that a farm management research/extension component had the highest marginal return among the categories considered. There is no obvious pattern among these findings: high and low rates were found for earlier years and later years and estimated rates varied when the same authors evaluated returns using different methods. Nor is there a particular pattern where one methodology routinely produces high estimates while others produce low estimates.

There are particular problems for estimating returns to extension. Over time, a larger share of extension funding has involved family, rural community, and nutrition activities. Whatever the benefits of these activities, they will not be reflected in the agricultural sector's productive efficiency. Therefore, to measure the returns to these activities requires that other measures of success be used. The data-reporting system for public extension expenditures is also less systematic than that for research expenditures.

Table 6—Returns to extension

Study	Period	Annual return (Percent)
Lu, Quance, and Liu, 1978; Lu, Cline, and Quance, 1979	1939-72[1]	24-31
Evenson, 1979	1949-71	110
Huffman, 1976 and 1981	1964	110
Huffman and Evenson, 1993	1950-82	20
Evenson, unpublished	1950-82	82-101

[1]Combined research and extension.

Source: Economic Research Service compiled from Huffman and Evenson (1993).

For public research activities, a standard set of categories for reporting research expenditures has been in place for many years. However, extension spending categories have changed significantly over time. The researcher who wished to analyze extension returns must make a variety of assumptions to generate a consistent time series of extension expenditures that relate only to productive efficiency.

There is a potentially severe problem of spillovers from the private sector that may lead to an upward bias in returns to extension. Considerable effort has been directed toward controlling for private spillovers from research but this has not been possible for extension. There are many private sources of information that compete with extension, such as farm cooperatives and farm input suppliers (seed, chemical, machinery, computer software firms) that provide information on how to use their products to improve farm productivity. There is also a newer development: firms specializing in providing farm services, such as pest scouting and nutrient management. The major difficulty in measuring private sector extension services is that these information services cannot frequently be separated from the sales of inputs and products.

Two important caveats are necessary in interpreting returns to the components of research. First, the measured returns are marginal rates. The expectation is that marginal rates decline as more funds are allocated to a research component.[10] Reallocating funds from a low-return component to a high-return component would drive down the return on the high-return component and drive up the return on the low-return component. Second, there are obvious complementarities among these components. Continued high returns to applied research, whether conducted by the public or the private sector, eventually depend on advances in basic research and in fundamental knowledge. Similarly, continued advances in basic understanding will not generate economic benefits unless applied R&D lead to commercialization of products, services, or practices.

The Estimated Social Rate of Return: Summary and Further Adjustments

Most studies of the social rate of return to public investment in agricultural research have consistently found

[10]Diminishing returns in one type of research can be offset by advances in knowledge achieved elsewhere. Over time, technological opportunities increase as fundamental knowledge increases.

high rates of return. Overall, the marginal rate of return seems highest for publicly supported basic, or pre-technology research, followed by applied public research, private research, farmers' education, and, finally, agricultural extension (table 7).

Some critics have suggested that the estimated rates of return may be biased upward (see Appendix). Six specific concerns include: (1) errors in estimates of the research lag; (2) failure to adequately take into account the contribution of the private sector to technology development and diffusion (spillovers from the private sector); (3) extra costs of funding research through general tax revenues (in economic terms the "deadweight loss" from taxes); (4) effects of farm programs that may create commodity surpluses and cause prices of agricultural products to diverge from their economically efficient levels; (5) negative environmental, health, and safety effects of new technology; and (6) extra costs associated with resource dislocation and adjustment. In the extreme, some studies have concluded that after adjusting for the upward bias, the rate of return to public agricultural research is comparable to that for other investments in the economy (Pasour and Johnson, 1982; Fox, 1985).

The results of new empirical work that addressed three of the above criticisms are presented in table 8. Our model considered possible research spillovers from the private sector, the extra costs of funding research through general tax revenues, and possible errors in the research lag. Our estimates suggest that studies significantly overestimate the rate of return if they fail to account for these factors. If none of these factors are included, then the estimated annual social rate of return to agricultural research between 1915 and 1985 was approximately 60 percent. After adjusting for these factors, the rate of return to all agricultural research was likely to be about 35 percent.

Table 7—Summary of social rates of return to agricultural research, extension, and education

Item	Core range	Full range
	Percent/year	
All public agricultural R&D	40-60	0-100
Basic public R&D	60-90	57-110
Private R&D	30-45	26-90
Agricultural extension	[1]	20-110
Farmer's schooling	30-45	15-83

[1]No evidence of a core range.

Sources: Economic Research Service derived from Ruttan (1982), Echeverria (1990), and Evenson (1993).

There is insufficient information to determine the net effects on the returns to research of the other issues raised, specifically effects of commodity programs, environmental externalities, and resource dislocation. Studies that have attempted to adjust for the effects of commodity program have often based these adjustments on simplified and generally unreasonable assumptions about how farm programs are managed (see Appendix). The net effect of new technology on the environment has not necessarily been negative. While the development of more intensive production methods may cause environmental degradation from the use of agricultural chemicals, it also reduces the need to expand production into environmentally sensitive lands. Furthermore, adjusting the rate-of-return estimates for environmental, health, and safety factors may not provide appropriate guidance for current research funding decisions. With environmental externalities, such adjustments would reflect pollution that was uncontrolled when the current technology was developed. However, these externalities now may be controlled through regulation, product approval decisions, and other environmental controls and not relevant for current research allocation decisions.

For resource adjustment, the effect of public agricultural research on labor displacement in agriculture is an unsettled question. Most research on agricultural machinery is conducted by the private sector. Sometimes public research may have contributed to labor displacement in agriculture (Schmitz and Seckler, 1970). However, other evidence suggests that the overriding factor contributing to the growth in average farm size

Table 8—Adjustments for biases in estimated rates of return

Adjustment	Central estimate	Range
	Number	*Percent/ year*
Unadjusted rate of return	60	55-65
Inclusion of private sector research	9	5-15
Tax collection (deadweight losses)	6	3-9
Longer research lag	10	0-20
Commodity program effects	n.a.	Negligible
Environment, health, and safety	n.a.	+/-
Structural adjustment, labor displacement	n.a.	+/-
Return after adjustment	35	

n.a. = Not available.

+/- = Effects could be positive or negative.

Source: Compiled by Economic Research Service as an extension of Yee (1992).

(and the decline in agricultural employment) in the United States has been the pull of higher wage, nonfarm jobs, rather than the push from new agricultural technology (Kislev and Peterson, 1982). It is also possible to have separate policies for providing for those who are disadvantaged. The primary goal of research is improving productivity and efficiency. Using R&D policy to try to correct income discrepancies could lead to more equitably distributed income, but at the cost of significantly slower productivity growth.

Policy Implications

Studies have consistently found that the net social returns to public agricultural research in the United States are high. Even after adjusting for possible upward biases in these estimates, the marginal social rate of return to public agricultural research is estimated to be at least 35 percent annually. The marginal rate of return to fundamental (pre-technology) research appears to be even higher, followed by applied public research, private research, farmer schooling, and agricultural extension. The estimated rate of return to agricultural research is high compared with estimates of the hurdle rate for public investments. The social discount rate or risk-free real rate of return is generally estimated to be between 3 and 5 percent. The return generally earned by investments elsewhere in the economy, another standard of comparison, is about 18-20 percent. It is likely that many more resources could be devoted to agricultural research before the marginal rate of return fell to either of these hurdle rates. Thus, agricultural research as a whole appears underfunded.

Comparing social rates of return for private versus public research also suggests that there is a unique role for public investment in agricultural research. The private sector often underinvests in agricultural research because only a share of the total economic benefits can be captured. This is most true of fundamental (pre-technology) research and is also true for applied research that generates important nonmarket benefits, such as environmental, social science, food safety, and nutrition research.

Empirical studies have also found evidence of large inter-State spillovers from agricultural research. Increases in agricultural productivity within a State result from research investment of both that State and of other States. One implication of inter-State spillovers is the need for Federal support in the financing of agricultural research. In determining the appropriate level of investment, policymakers at the State level may consider only the benefits to the State and ignore benefits that could be transferred to other States. Thus, the investment by States would generally be less than the socially optimal level of investment (based on returns to the Nation as a whole). This is the rationale for the requirement that State governments match Federal formula funds provided to State institutions for agricultural research. Spillovers also occur globally. U.S. support of international agricultural research can have important reciprocal benefits for American agriculture.