Staff Paper Series

Staff Paper P69-5 April 1969

THE RETURNS TO INVESTMENT IN AGRICULTURAL RESEARCH IN THE UNITED STATES

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* A paper prepared for the Symposium on Resource Allocation in Agricultural Research, University of Minnesota, Minneapolis, Minn., February 23-25, 1969. The author wishes to acknowledge the helpful comments of Zvi Griliches on a previous draft of the paper.

January 10, 1969

To: Participants in the Resource Allocation in Agricultural Research Symposium

From: Willis L. Peterson
Department of Agricultural Economics
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Enclosed is a copy of the paper I have prepared for the symposium.

The Returns To Investment in Agricultural Research in the United States

Willis L. Peterson

With the passage of the Hatch Act in 1887, establishing state agricultural experiment stations, the program of publically supported agricultural research in the United States was set in motion. By today's standards the program began small; each station was allotted $15,000 per year in public funds resulting in an annual agricultural research bill of about three-quarters of a million dollars (undeflated) for the entire country. The record of growth of U.S. agricultural experiment stations since 1887 is well known. Expenditures for research at experiment stations currently totals about $225 million per year. [1] Taking into account research carried on by the U.S. Department of Agriculture and the expenditures for agricultural extension work, about $125 million and $150 million per year respectively in the early 1960's, results in a total public expenditure for the production and distribution of knowledge in U.S. agriculture of over one-half billion dollars per year in recent years. [2]

Although we have relatively little information on industrial R and D related to agriculture it is estimated to be about the order of magnitude of agricultural research supported by public funds. [3] Thus it appears that the total value of resources devoted to the production and distribution of knowledge for U.S. agriculture is in the order of magnitude of one billion dollars per year currently. In view of the sizable and growing amoung of resources devoted to agricultural research and extension it is reasonable to expect efforts to evaluate the returns to this investment.

The principle aim of this paper is to review and compare the results of recent empirical studies on the measurement of returns to investment in agricultural research in the United States. We will be concerned primarily with publically supported research although industrial research is taken account of when estimating returns. We will begin by looking at some of the more descriptive, "public relations" approaches of evaluating agricultural research and then turn to the more quantitative, analytical efforts that appear in recent literature.

Public Relations Approach

By this approach we have in mind those efforts that describe in general terms what research has accomplished and/or what it is expected to accomplish in the future. The manner of description varies. It may concentrate on immediate results such as progress toward or development of a new disease resistent variety of wheat, new insights gained on what constitutes a balanced ration or knowledge gained about the attitudes of farm people, etc. Or this approach may strive for more quantification by presenting figures such as additional units of output because of higher yields that were made possible by research, or dollars saved by farmers because of reduced insect damage, etc. In the case of extension, the most popular technique is to present the number of people contacted. The literature abounds with this kind of research evaluation beginning back at the time of the Hatch Act and continuing up to the present. [4/]

Of course it is a relatively easy task to criticize this approach. But before we do so it seems that we might say something in its defense. Since it has persisted so long and is still used widely, it must have some advantages. For one thing it is relatively cheap and easy to do. Project proposals and progress reports provide the background information. From this point the scope of the evaluation is limited only by the imagination of the evaluater, which often turns out to be the researcher himself.

Perhaps the main advantage of this descriptive and sometimes persuasive type of evaluation is that it is generally appealing to the public and is easily understood. For research that depends upon public support, it is important that the public have some idea of what is being done and hopefully have a favorable impression about the importance of the work. Phrases such as "internal rate of return" or "benefit-cost ratio" which are generally associated with more analytical approaches do not seem to have the power to persuade the public or their elected representatives as do phrases such as "did pioneer work on" or "helped pave the way for" which often appear in the so-called public relations type of evaluation. It appears therefore that as long as the public through their elected representatives has something to say about the amount of resources devoted to agricultural research we will continue to see these public relations efforts.

On the other hand, exclusive reliance on this approach envolves some problems. First, it probably gives the public a distorted view of the research process. The common characteristic that seems to permeate most research evaluation of this kind is the success of the research effort. Yet we know, of course, that not all research is successful in the sense that something is learned or accomplished in every project. In fact, it is quite possible that only a small percentage of research projects are successful, perhaps not over 10 to 15 percent. In other words, research can be viewed in the context of oil exploration where 8 or 9 dry holes are drilled for each one that strikes oil. In research the percent of success might increase as one moves away from basic towards applied or the development type of activity, although even this is not certain. This not to say, however, that failures negate the successful research. A handsome return on all research can be obtained in spite of the failures. The point is that the descriptive, public relations approach of research evaluation generally implies a high return to all research which would seem to give a distorted view of the research process.

A second problem of this approach is encountered when it is used to evaluate the results of a research program. An example of this problem is illustrated by an attempt in 1937, the fiftieth anniversary of the Hatch Act, to evaluate the achievements made possible through grants under this act [2]. The following descriptive phrases appear in the report:

> "threw light one", "contributed to the improvement of", "made important contributions on", "helped lay the foundation for", "contributed largely to the knowledge of", "did pioneer work on", "stimulated new lines of investigation in", "helped pave the way for", "did outstanding work on", "labored effectively in"

These phrases were used to describe the results of 50 years of research in the plant and animal sciences and in the mechanization of agriculture. Only one sentence contained a pessimistic note and this came in regard to agricultural economics and rural sociology where the author noted, "there is nothing to report" (there were about 300 agricultural economists in colleges of agriculture at that time). In spite of the apparent lack of success in agricultural economics one is left with the impression that agricultural research up to that time had been quite successful. But evidence which we now have suggests that the first 50 years of agricultural experiment station research may not have been as successful as this report would lead us to believe.

If we view research as activity which produces new knowledge which in turn results in new, more efficient inputs, then the logical outcome of research is increased productivity as measured by output per unit of input [5]. Yet from 1900 to the mid 1930's there was no apparent sustained increase in productive efficiency of U.S. agriculture (table 1).

Table 1. Index of Agricultural Productivity in the United States, Selected Years, 1957 - 59 = 100

Year	Output/input	Year	Output/input
1900	66	1940-44	79
1910-14	61	1960	105
1930-34	65	1966	108

Source: "Changes in Farm Production and Efficiency", U.S. Dept. of Agriculture Stat. Bul. No. 233, 1967, p. 17.

If indeed these figures depict the true situation in agriculture during the 1900-35 period, then it is at least a possibility that reports such as the one just quoted did a good job of making it appear that this rather significant outlay of public funds was paying off handsomely. Total expenditure on research in the experiment stations from 1887 to 1937 came to $237 million in current prices ($538 million in 1959-60 prices) and extension expenditures under the Smith-Lever Act of 1915 totalled $424 million in current prices ($832 million in 1959-60 prices) from 1915 to 1937. [6]

The question why the first 50 years of agricultural research seemed to lack any impact on agricultural productivity is still unanswered and to explore this topic adequately would lead us away from the main purpose of the paper. In passing, we might mention that a number of possible explanations exist any or all of which may be true.

These include:

1. Research was too superficial during these early years with the result that it turned out information already known to farmers. [7]

2. A long period of time is required to build up a stock of knowledge that is necessary to made progress in applied research.

3. Without research agriculture would have experienced a significant decline in productivity because of the closing of the frontier and subsequent depletion in soil fertility and increase in disease problems. In this case research would have a pay-off even without an increase in productivity.

4. Problems of data collection during this period could have biased inputs upward or output downward giving the impression of zero productivity growth when in fact growth had occurred.

Whatever the reason for the apparent stagnation of agriculture during the early 1900's, the main point to be made here is that a highly favorable "public relations" account of research accomplishments can be consistent with either a positive or zero contribution of research to production.

A third problem of this approach envolves a common misunderstanding of the ultimate beneficaries of agricultural research. The arguments put forth in the 1880's in behalf of the proposed Hatch Act and the description of agricultural research accomplishments since then center largely on the idea that research benefits farmers by enabling them to increase output and/or conserve on inputs. But it is one thing to increase corn production by a million bushels or save farmers a million dollars in expenses and quite another thing to increase farm income by a million dollars. Because of the inelastic demand for farm products,and the highly competitive nature of agriculture,increasing agricultural productivity, other things constant, tends to depress farm prices and reduce total revenue going to farmers. A strange benefit indeed for farmers.

Instead it is more appropriate to view the benefits of research as a reduction in the real cost of agricultural products to consumers over what it would be without the research and associated productivity gains. To be sure, farmers gain as consumers but so does everyone else in the economy. Granted, of course, some farmers are able to reap short run pure profits by early adoption of new inputs or techniques which explains why many are eager to adopt new inputs or techniques developed by research. Nevertheless if the main value of the public relations approach is to insure continued support of agricultural research, it would do better to expound the benefits accruing to the nonfarm public -- those who pay the major portion of the agricultural research bill today.

A fourth and perhaps most serious drawback of this approach is that it does not yield any information that is useful in achieving an efficient allocation of resources. The fact that there are some positive benefits of research only implies that its marginal product is greater than zero, or that it yields a positive rate of return in the context of an investment. But for most investment the question is not whether the benefits are positive, but whether or not benefits are greater than the cost. Is the rate of return of research funds greater than or equal to the returns obtainable in alternative investment? The purely descriptive, public relations technique of research evaluation may attempt to leave an impression that the return exceeds the cost but cannot show that it is.

We now move on to the more quantitative methods of evaluating the returns to investment in agricultural research. The pioneering work in this area must be credited to T. W. Schultz and Zvi Griliches. The initial discussion will center on efforts to evaluate agricultural research in the aggregate. Then we will turn to a couple of efforts at commodity wide evaluation of research, namely hybrid corn and poultry.

Value of Inputs Saved

The dollar cost of agricultural research carried on in the experiment stations and agencies of the U.S. Department of Agriculture is relatively easy to obtain. Thus, setting aside for the moment problems of deflating and discounting costs, the main defficulty comes in the quantification of research benefits. One technique, that used by Schultz [8, pp. 114-22], is to calculate the value of inputs saved in agriculture because of improved, more efficient production techniques. As a lower limit Schultz estimates that output per unit of input was 32 percent higher in 1950 than in 1910. Thus to have produced 1950 output, which employed about $30,000 million of resources, with 1910 techniques would have required $9,600 million ($130,000 million X .32) additional resources.

In the interest of presenting a conservative estimate of research returns over costs Schultz assumes that the current (1950) level of public research and extension extends back to 1910. Even with the large overstatement of research and extension expenditures which adds up to $7,000 million over the 40 year period, we see that the saving in inputs for 1950 alone ($9,600 million) is substantially greater than all public research and extension expenditures from 1910 to 1950.

We are warned, however, about two possible biases in this procedure. (1) Some of the public expenditure, particularly extension, is allocated to activities not specifically aimed at producing and distributing new production techniques. As a consequence measuring only resources saved may bias downward the net returns to research and extension. (2) Part of the improvement in production techniques should be attributed to the research of industrial firms and individuals. Neglecting these expenditures of course, would bias estimated net return to public research and extension upward.

We might carry the analysis a bit further by using Schultz's technique to compare the cost and returns of research up to the 1950's with cost and returns up to the present time. Utilizing available data we carry expenditure on experiment station research back to 1910 and expenditure on USDA research and cooperative extension work back to 1915. As shown in table one, a sustained rise in agricultural productivity did not begin until the mid 1930's. Thus on the returns side, estimated annual value of inputs saved begin in 1937 and continue up to the present (most recent data are available for 1966). Estimates of public expenditure on research and extension and value of inputs saved, both in constant 1957-59 dollars, for selected years are presented in table two.

The results obtained from more recent data present even a more favorable picture for agricultural research than was the case in the early 1950's. The sum of all public research and extension from 1910 through 1950 was $3,757 million,

Table 2. Estimates of Public Expenditure on Research and Extension and Annual Value of Inputs Saved, U.S. Agriculture, Selected Years. (1957-59 dollars)

Year	[a]R + E	[b]Inputs saved
	($mil)	($mil)
1910	8	--
1930	96	--
1940	168	2,034
1950	195	10,110
1960	364	20,623
1966	*450	26,387

a. Source: Experiment station expenditures: "Annual Report on the Experiment stations" respective years, USDA and Extension expenditures: Latimer /5/.

b. Calculated by multiplying percentage change in output per unit of input from 1900 to each year times value of resources employed in agriculture in that year. Indexes of productivity obtained from "Changes in Farm Production and Efficiency", U.S. Dept. of Agri. Statistical Bulletin, No. 233, June 1967.

* Estimate

and the value of inputs saved in 1950 alone was equal to $10,110 mil. in 1957-59 prices. However, the research bill from 1910 through 1968 amounts to $9,887 million whereas the estimated value of inputs saved in 1966 alone is equal to $26,387 million.

Viewing these figures in another way we see that from 1950 to 1968 the total research bill increased by $6,130 million while the total value of inputs saved from 1950 through 1966 increased by over $300,000 million. It appears, therefore, that the value of inputs saved is rising considerably faster, in absolute terms, than investment in agricultural research and extension. In other words, these figures suggest that we may still be in the region of increasing returns as far as total agricultural research and extension is concerned. This is not to argue, of course, that allocating more and more funds to a given project or even a given discipline will insure increasing returns.

The warnings expressed by Schultz regarding possible biases in these cost and returns estimates still hold. Some research and extension is not intended to increase productivity. Also we should bear in mind that industrial R & D and extension undoubtedly affects agricultural productivity. Although if we assume that private R & D in agriculture is roughly equal to public investment for each year, the total since 1910, $19,774 million, is still less than the saving in inputs for 1966 alone. And we must also keep in mind the positive effects on production from improved skills of farm people. To give sole credit for inputs saved to research and extension neglecting investment in education, both general and vocational, is to impute a higher return to research than is legitimate. We shall turn shortly to some efforts to handle this problem.

Before leaving the subject of possible biases in this technique, we should be aware of one additional bias that could result in a substantial underestimate of the returns to research. In this procedure, there is an implicit assumption that without research agricultural productivity would remain constant. However, from what we know about the production process in agriculture it appears that in many areas there must be a constant flow of new knowledge or inputs into the industry just to stay even. We have in mind, here, such things as new disease resistent varieties of crops which replace those that have become susceptible to new viriuses. A similar situation exists in livestock production.

Thus to be strictly correct we should measure the productivity gain for a current year not as the change in output per unit of input from some past base year but rather as the change from what would exist without research to the present situation. Of course we cannot know latter figure so we have to settle for the former.

External and Internal Rates of Return

The approach of comparing costs of research with the derived benefits is useful to obtain a general idea of payoff to research expenditures. We can, however, derive a somewhat more precise measure of the return by computing a rate of return, thereby allowing a more direct comparison with other types of investment in the economy. There are two separate rates of return that can be computed.

The first we shall call the "external rate of return" for lack of a better term. With this procedure the flow of costs and returns are accumulated (or discounted) to a point in time using a rate of interest that presumably reflects the opportunity cost of capital in the economy. 8/ The research costs are expressed as an accumulated capital sum. The returns (value of inputs saved) are also accumulated to the same point in time but then expressed as a perpetual flow.

Using 10 percent as the rate of discount, together with the estimates of research and extension expenditures and inputs saved as presented in the previous section let us compute the external rate of return to this investment. In order to take account of private research we shall multiply annual public research and extension by a factor of 2. The flow of returns extends from 1937 into perpetuity with the 1966 level of net returns (inputs saved minus research and extension costs) assumed for all years after 1966. This assumes that after 1966 research only maintains the level of productivity. This is a rather conservative assumption which should result in a conservative estimate of the rate of return. The stream of research and extension extends from 1910 to 1966. [9/]

The resulting figures for computing an external rate of return to this investment are:

	($billion)
1. Cumulated past returns	$1,238.1
2. Past returns as an annual flow	123.8
3. Annual future returns	25.4
4. Total annual returns (2 + 3)	149.2
5. Cumulated past research expenditures	200.2
6. External rate of return (100 X 4/5)	75 %

This 75 percent external rate of return, together with the 10 percent discount rate used can be interpreted to mean that the average dollar invested in agricultural research and extension (public and private) has returned 10 percent annually in terms of resources saved to society from the date of investment to 1966 and is now paying off at the rate of 75 percent per year for all time to come. If a lower rate of discount were used, say 5 percent, the annual past return to each dollar would be reduced to 5 percent but the annual future returns would be higher.

As Griliches has pointed out this rate of return is closely related to the benefit - cost ratio. [10/] The formula for converting from this measure to the B/C ratio is given by $B/C = r/100k$ where r is the external rate of return and k is the rate of discount, .10 in the previous computation. Thus we obtain a B/C ratio of 7.5 meaning that the average dollar spent on agricultural research returns 7.5 dollars in social benefits (inputs saved).

Thus the B/C ratio and the external rate of return are just two ways of expressing the same figure. The internal rate of return, however, has a slightly different meaning. It can be defined as that rate of interest which makes the discounted present value of the flow of costs equal to the discounted present value of the flow of returns at a point in time. The internal rate of return (r) is calculated by an iterative process and can be expressed as that rate which results in $\sum_{t=0}^{i} \frac{1}{(1+r)^i} F_i = 0$ where F is negative as a cost and positive as a return. Applying the flow of agricultural research and extension costs and the returns (inputs saved) to this formula results in an internal rate of return of about 19 percent. This means that on the average each dollar invested in U.S agricultural research and extension returns 19 percent annually from the date of investment.

Even though there is a rather large difference between the external and internal rates, 75 percent compared to 19 percent respectively, it should be made clear that both figures have to mean the same thing since they are both derived from the same cost and returns data. The internal rate turns out to be lower because of the long "gestation period", 1910 to 1937, when costs were being incurred but no measurable returns were showing up. The internal rate of return is quite sensitive to the length of this period. The main point is that we should be aware of which return we are dealing with and interpret the figure accordingly.

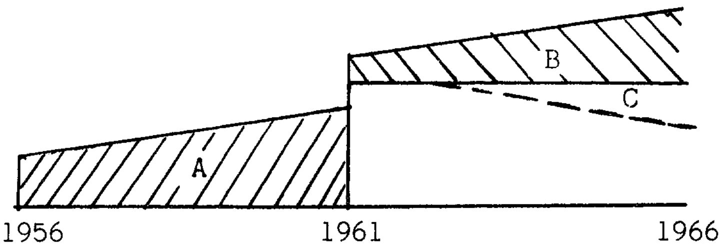
Average Versus Marginal Rates of Return

It should be stressed as well that the returns we have just computed are average returns to past investment in agricultural research. But we might seriously question whether an average return is an appropriate measure for this kind of investment. For an investment such as a hydro-electric project, a bridge, or a road, an average return would seem to be more appropriate. Because in "all or none" decisions such as these once the initial decision is made to invest there is little chance for marginal decisions later. For example, a government does not decide initially to build a bridge half way across a river and then decide later whether or not to extend it to the other side. In this case we are interested in the average return to the total investment in the bridge, not in the return to investment in a marginal plank.

In research, however, the situation is quite different. Each time period marginal decisions must be made to invest or not to invest. And in economic decisions, as we know, by-gones are by-gones. The return to investment in 1940 or 1950, for example, should not influence the decision to invest today. What we need, instead, is information on the return to additional investment - a marginal rate of return.

We might derive a rough, first approximation of a marginal return from the data represented in Table 2. Let us assume that the <u>increase</u> in agricultural productivity over 1960 from 1961 through 1966 resulted from the total investment (public and private) in agricultural research and extension during the previous 6 year period, 1956-1961. In terms of the following diagram, the costs are represented by area "A" and the returns by area "B". Let us assume also that the level of returns obtained in 1966 will continue into the future.

Figure 1



Cost (research and extension) and returns (inputs saved) figures are presented in table 3.

Table 3. Investment in Agricultural Research and Extension, 1956-61, and Value of Additional Resources Saved, 1961-1966.

(1957-59 dollars)

Year	Total R + E	Year	Additional Inputs Saved over 1960
	($ mil)		($ mil)
1956	$ 531	1961	$ 1252
1957	600	1962	2284
1958	636	1963	4871
1959	683	1964	4139
1960	727	1965	6705
1961	811	1966	5764

Computing an internal rate of return to this stream of costs and returns, i.e. that rate of interest which makes area A equal to area B at a point in time (1966), yields a figure of about 45 percent. Thus it appears that investment in research and extension has been paying off at a higher rate in more recent years than it has over the entire period since 1910, 45 percent compared to 19 percent. In other words, agricultural research and extension in the U.S. seem still to be in the region of increasing returns.

Of course the potential biases mentioned in the preceding section apply also to this "marginal return". Failure to include the cost of increasing the educational level of farmers likely overestimates the returns. Also it is assumed that the returns will continue on into the future at the 1966 level. This assumption probably biases the returns upward also because of the likelihood that the knowledge will depreciate and futures returns decline. On the other hand, the estimated returns from 1961 to 1966 may be too low because without the 1956-61 research the level of productivity may have diminished. If so a more accurate measure would be to show a larger immediate return including areas B + C in figure 1 as returns. Quite possibly these last two biases come close to cancelling out.

Marginal Product of Research

An additional step forward in the estimation of the marginal returns to agricultural research is accomplished by Criliches in his study which included agricultural research as a separate variable in an aggregate agricultural production function [4]. Also the effect on output of the level of skills of farm people is estimated by including an education variable in the production function.

The marginal product of public research and extension is estimated to be about $13. Assuming, as Griliches did, that industrial research is roughly equal to public research divides the marginal product in half, down to $6.50. Also, as a further adjustment, it is assumed in this study that because of government programs the social value of additional agricultural output is one half of market value. This yields an adjusted marginal product of about $3.

In order to make the Griliches results comparable to the rate of return calculation of the preceding section, let us convert the $6.50 marginal product into an internal rate of return, assuming 6 year lag between the expenditure and the beginning of a return. If we assume that the return continues into perpetuity the internal rate equals 53 percent. On the other hand, assuming a once and for all return in year 6 yields a return of 36 percent.

Both of these assumptions, however, probably over-simplify the true situation. Recent work by Robert Evenson [1] indicates that the returns to research are likely to be distributed over a period of time, first increasing as knowledge is generated and adopted and then declining as the knowledge depreciates. In other words, the flow of returns resembles an inverted "V". Evenson's study reveals that the mean lag (high point of the inverted "V") for state supported research is about 5½ years and 8½ years for federally supported research. These results provide the basis for assuming the 6 year lag in the preceding computations. The simple approach of assuming zero returns for 6 years no doubt underestimates the immediate return. On the other hand, assuming a return into perpetuity clearly overestimates the return in the future. However with a high rate of discount the future returns do not carry a large weight. At any rate, as we will see, the inverted "V" technique yields a return not greatly different from what we obtain using the more simplistic approach.

Evenson also provides us with some estimates of the marginal return to agricultural research and extension. In a time series linear regression model with a productivity index as the dependent variable, the coefficient on the public research and extension variable yeilds an internal rate of return of 57 percent. [11] Adjusting the coefficient for private research reduces this estimate to 48 percent. Additional estimates are made by fitting a Cobb-Douglas aggregate agricultural production function to cross section data (similar to the Griliches model) using alternative forms of the research variable. One specification separates "applied", production-oriented research from the more basis type such as research on genetics, soils, botony, etc. By in large these estimates of the marginal product of research also yield internal rates of return in the range of 40 to 60 percent.

Contribution to National Economic Growth

Thus far we have discussed two general approaches of evaluating agricultural research. The first utilizes an index of productivity in agriculture in order to obtain a measure of resources saved due to increased efficiency in production. Second, in the production function approach, research is incorporated as a separate variable in an attempt to measure its marginal product. Tweeten and Hines provide us with a third way of evaluating the effects of research and education on agriculture /10_7. The basic idea of their approach is that increased agricultural productivity has released human resources from farms. This, in recent times a smaller proportion of our population is required to produce food leaving more people to produce other goods and services. The basic idea is similar to the inputs saved approach of Schultz. Although the measurement technique is quite different. [12]

The estimated returns to increased agricultural productivity in 1963 is calculated by estimating what 1963 national income would have been if the proportion of people living on farms had not changed since 1910. In 1963 percapita income of farmers was $1302 compared to $2639 for nonfarmers. Thus if all people had received the farm level ($1302) percapita income in 1963, national income would have been only $247 billion. Or, if everyone had received the nonfarm level, national income would have been $500 billion. The actual level of national income in 1963, $482 billion, is then a weighted average of these two figures, weighted by the proportion of population in each sector, i.e., .071 ($247) + .929 ($500) = $482 billion. If the 1910 distribution of the population had prevailed in 1963, .347 farm and .653 nonfarm, the 1963 national income would have been .347 ($247) + .653 ($500) = $411 billion, or $71 billion lower than the observed figure.

On the cost side the authors include much more than we have considered thus far. In addition to research, vocational education, and extension, $.8 billion annually, they include $2.7 billion for primary and secondary education in rural areas, $3.5 for farm program expenses, $2 billion for urban education that would likely affect agricultural productivity, and $1 billion for miscellaneous items such as higher education and roads. The annual total comes to about $10 billion. Presumably this would be for a year in the early 1960's.

To convert these cost and returns figures into a benefit-cost ratio, the authors estimate that an additional $10 billion in research, education, etc., enchances national income by about $1000 to $1500 million per year into perpetuity. Discounting the returns back at 5 percent, they derive a present value of $20 billion for the lower estimate of returns. This equals a benefit-cost ratio of 2. But a B/C ratio of 2 is equal to an "external" rate of return of only 10 percent if a 5 percent rate of discount is used. There seems to be some discrepancy between the conclusion drawn in the article that the returns to research are high and the figures obtained. A 10 percent return is quite close to a normal rate in the economy. Since costs are estimated only for a current year (1963) it is not possible to compute an internal rate of return with a lag between costs and returns.

The low B/C ratio or external rate of return seems to be due mainly to the large estimated costs -- over 10 times the annual expenditure on agricultural research and extension at that time. Much of these costs probably affect the nonagricultural sector as much as agriculture so it may be asking too much of agriculture to carry the entire $10 billion. Nevertheless, this technique for measuring returns is somewhat different than what we have seen thus far so it will be useful to examine it more closely.

First it is important to recognize that measured returns depend on the extent of (1) the disequilibrium between percapita farm and nonfarm earnings and (2) the rate of farm to city migration. The larger the gap in earnings and the higher the rate of migration, the higher the returns to agricultural research, extension, etc. as measured by this procedure.

One problem is that $3.5 billion farm program costs adversely affect the measured returns. Presumably farm program payments raise farm income relative to nonfarm income and reduce the migration from farm to city. But both of these reduces the measured returns to research. Thus, one implication of this procedure is that farm program expenditures enter at a negative rate of return. If these payments were large enough so that there were no farm-nonfarm income differential there would be no measured returns to research.

In addition, the incremental returns to research as measured by this technique approaches zero as the farm population approaches an equilibrium.

This must happen, or course, since the number of farmers cannot fall below zero.

Also in the early part of the period, 1910 to 1930, this technique probably overestimates the returns to agricultural research. As shown in table 1 of the Tweeten and Hines article, the annual contribution to national income of research during the 1910-30 period is about one billion dollars per year. This is roughly the same as is shown for the early 1960's. Yet from the input-output data for agriculture we observe no change in agricultural productivity during the 1910-30 period and a substantial increase in the late 1950's and early 1960's, (table 1). For the early 1900's the returns probably reflect higher earnings of nonfarm people and the subsequent migration from agriculture offset by the substitution of capital for labor in agriculture.

One further problem with this approach is that it assumes the same farm and nonfarm income levels for the base year and current year population distributions. However it seems reasonable to expect that both farm and nonfarm income levels would be lower under the base year population distribution. In fact, this also is a basic assumption of the approach. If farm to city migration contributes to economic growth then, by definition, per capita incomes are higher. Therefore, it is likely that assuming constant income levels for the two population distributions would bias the estimated returns downward for the entire period.

Thus far we have been concerned with returns to agricultural research in the aggregate. Let us now examine two studies at the commodity level: hybrid corn and poultry. The hybrid corn study by Griliches /3_7 is the forerunner of most recent attempts at quantifying research returns, and, as noted, forms the basis for much of the preceding discussion in this paper.

Hybrid Corn Research

The really difficult part of estimating a rate of return to research is measuring the output of research. In this regard Griliches calculates the loss in "consumer surplus" to society that would occur if hybrid corn were to disappear. It is assumed here that adoption of a new, more productive input such as hybrid corn will shift the supply curve of the product downwards and/or to the right. Thus the returns are calcualted as the area under the demand curve between the actual and hypothetical (without the new input) supply curves.

The estimated returns will vary slightly according to what is assumed about supply and demand elasticities of the product. Griliches shows that a perfectly elastic supply, as in figure 2, results in the lower bound of the eatimated returns, and a perfectly inelastic supply results in an upper bound (figure 3).

Figure 2

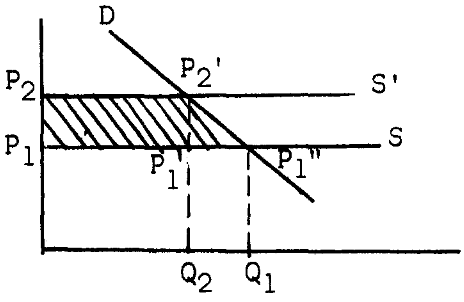
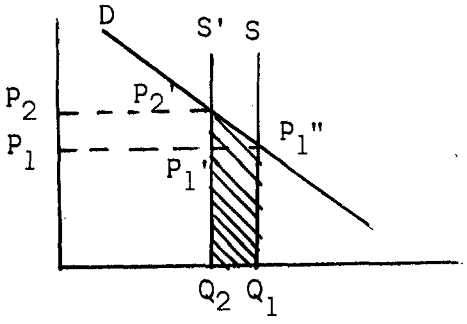


Figure 3



The formulas for the estimated returns, shaded areas in the figures are:

figure 2: $K P_1 Q_1 (1 - \frac{1}{2} K n)$

figure 3: $K P_1 Q_1 (1 + \frac{1}{2} K/n)$ 13/

Where "K" is the increase in productivity from a base year and "n" is the demand elasticity of the product. Griliches uses the first formula in order to obtain a lower bound of estimated returns. Of course, if "n" is small the entire expression is approximately equal to $K P_1 Q_1$, which is the formula used by Schultz in calculating resources saved, shown in table 2. If, for example, we assume the aggregate demand elasticity for agricultural products is .1 the value of resources saved for 1966 is $25.6 billion using the formula from figure 2. This compares to the $26.4 billion shown in table 2 using just the $K P_1 Q_1$ part of the formula.

On the other hand, in the second formula (figure 3) a small demand elasticity such as .1 results in a four-fold increase over the figure obtained in the simple $K P_1 Q_1$ expression ($26.4 billion). This is expected since the figure 3 formula approaches infinity as "n" approaches zero. It appears therefore that the figure 3 (upper bound) formula is not a good one to use in estimating consumer surplus. This is not so much because it gives an upper bound, to estimated returns but because a substantial error in estimated returns can result from a small error in the estimated elasticity of demand.

At any rate, the most striking finding of this study is that past investment in hybrid corn research is now yielding a rate of return of 743 percent. This 743 percent figure is often quoted but seldom interpreted. It should be kept in mind that this is an external rate of return where each dollar yields 5 percent annually up to the cut-off date (1955 in this study) and 743 percent thereafter. The internal rate of return in this study is about 37 percent. Both of these (external and internal) are average rates of return.

Griliches also estimates a rate of return to hybrid sorgum research and in so doing illustrates an important point. If a given expenditure results in equal gains in productivity in two or more alternative products the rate of return is maximized if the research expenditure is devoted to the product with the largest absolute output. In the case of hybrid sorgum the same increase in yield is assumed as for hybrid corn (15 percent) but the estimated rate of return to hybrid sorgum research is only half of the return to hybrid corn research even though the expenditures on sorgum are considerably smaller than on corn. Again this is expected because of the P_1 Q_1 in the formula.

Poultry Research

A more recent study utilizes both the hybrid corn procedure (referred to as the index number approach) and the production function approach to estimate the returns to poultry research /6/. In the index number approach the formula for estimating consumer surplus is generalized somewhat. In the Griliches formulation it is implicitly assumed that the demand elasticity is unity because the relative distance between P_1 and P_2 is assumed to be the same as that between Q_1 and Q_2 (figures 2 and 3). However, refinements over the Griliches formula or even over the simple K P_1 Q_1 expression tend not to affect the results greatly because they include mainly second-order effects.

The biggest problem with the index number approach is to obtain a measure of productivity gain that reflects only the output of research. In the hybrid corn study the increase in yields due to hybrid corn was assumed to be 15 percent. The measurement of productivity gains in poultry due to research was somewhat more difficult, however, because of the more inclusive definition of research in this study. Hence there were several possible sources of productivity gains to identify. Two alternative measures of productivity gains were used: (1) gains in feed efficiency and (2) the decline in poultry product prices relative to poultry input prices. It is argued that both measures bias the returns to poultry research downward with the largest bias probably in the relative price procedure. At any rate the average internal rate of return to poultry research and extension in the United States is estimated to be about 18 percent using the feed efficiency measure of productivity.

This 18 percent return applies to the sum of public and private research and extension. However, as pointed out in the study, the procedure envolves some double counting of private research. In estimating the net social returns to poultry research the value of new, purchased inputs is subtracted from the gross value of consumer surplus. However, it is reasonable to believe that the value of purchased inputs already includes a return to private research. Thus if we define the social return as including a private return to private research this procedure underestimates the social rate of return because private research is charged twice, once on the returns side because it is subtracted along with the value of new, purchased inputs and again on the input side because it is included in total research expenditure.

The production function approach envolves fitting an aggregate poultry production function with experiment station research on poultry included as a separate variable. Taking into account USDA and industrial research and extension yields a marginal product of about $6.00. In order to convert this into an internal rate of return, a 10 year lag is assumed between research input and its returns. This results in a marginal internal rate of return of about 33 percent. However, in view of Evenson's work on lags, 10 years may be a bit too long. Let us assume a 6 year lag instead as we have done for the previous studies mentioned. In this case the marginal internal rate of return is about 50 percent. Thus, again we have a case where the marginal return exceeds the average.

One final distinction should be made between the poultry and the hybrid corn study. The latter includes only the cost of hybrid corn research, a very successful venture, whereas the former includes all research pertaining to poultry production. Thus we would expect a higher return, in the hybrid corn study. And this is what we see comparing the average internal rates of return, 37 percent for corn compared to 18 percent for poultry. This is not to argue that one is more correct than the other. The main point is that one must be aware of what is being measured when comparing the results.

Summary of Rates of Return

Since we have covered a variety of different studies and approaches, a summary of the returns is presented in table 4. In order to gain comparability between studies only internal rates of return are quoted. However, these include estimates of both average and marginal rates. A 6 year lag is assumed between the expenditure and the beginning of the returns, except in the Evenson study which utilizes the inverted "V" distribution of returns. Also both public and private research is included in all estimates as well as extension.

In view of the diversity of techniques and data employed it is somewhat comforting to observe the relatively small dispersion of the estimates, particularly for the marginal returns. As for the average returns, the hybrid corn study is not strictly comparable to the other two estimates because it

Table 4. Summary of Studies Estimating Average and Marginal Internal Rates of Return to Agricultural Research and Extension in the United States.

	Average return (percent)	Marginal return (percent)
1. Schultz, inputs saved technique extended for this paper.	19	45
2. Griliches, aggregate production function, cross section data.	--	53
3. Evenson, linear regression on residuals, time series data.	--	48
4. Griliches, hybrid corn study.	37	--
5. Peterson, poultry study.	18	50

encompasses a narrower area of very successful research. At any rate, the overall conclusion seems clear; the return to agricultural research and extension in the United States is high relative to more traditional investment. And the evidence also supports the hypothesis that the return in recent years is even higher than the return two or three decades ago.

Future Allocation of Research

The studies we have mentioned are, of course, very aggregative. How can the information from these studies help the research administrator make day to day decisions about where to allocate available research funds? The answer probably is that they do not help him, nor are they intented to. What they probably do however, is to help research administrators obtain funds that they then can allocate. If those in charge of allocating public funds at the aggregate level, legislative bodies mainly, are interested in maximizing the return to these funds, then presenting them with information on rates of return in the area of 40 to 50 percent should bring forth more funds to agricultural research than if 5 to 10 percent rates are obtained. This assumes, of course, that there is a response to this information.

We must recognize, of course, that other things influence the amount of funds allocated to agricultural research besides information on rates of return. One important factor is the state of the economy. For example, during the great depression of the 1930's we observe a reduction in agricultural research funds (table 5). We can observe the same thing cross sectionally where the high income, urban-industrial states support agricultural research more generously than do the lower income, agricultural states [7]. In other words, knowledge seems to be a superior good.

Table 5. Public Funds for Agricultural Research and Extension in the United States
(1957-59 dollars)

Depression Years	($ mil)	World War II Years	($ mil)
1932	$116.6	1939	$170.0
1933	109.3	1940	167.5
1934	95.4	1941	149.6
1935	94.8	1942	137.3
		1943	131.5

Another factor affecting agricultural research is the military needs of our society. As shown in table 5, agricultural research declined substantially during World War II. The same thing is observed in the Korean conflict. In our society the military has traditionally ranked ahead of agricultural research on the priority scale. In retrospect this seems to have been an unwise policy in view of the crucial role of food in military operations, especially during the World War II years.

Thus there seems to be a definite functional relationship between income generated and agricultural research, and between higher priority needs and research. As yet we do not have a test of the hypothesis that there is a positive relationship between information on the rate of return to agricultural and public appropriations. As economists about all we can do is present the information and hope.

Footnotes

1/ Source: 1889-1953 "Report on the Agricultural Experiment Stations," Office of Experiment Stations. U.S. Department of Agriculture.

1954-60 "Report on the Agricultural Experiment Stations," Agricultural Research Service, U.S. Department of Agriculture.

1961-present "Funds For Research at State Agricultural Experiment Stations," Cooperative State Experiment Station Service, U.S. Department of Agriculture,

These figures include federal and nonfederal funds available for research less fees and sales.

2/ Source: Robert G. Latimer, "Some Economic Aspects of Agricultural Research and Education in the United States," Unpublished Ph.D. dissertation, Purdue University, 1964, Tables 3 and 5.

3/ "A National Program of Research for Agriculture" Report of a Study Sponsored Jointly by: Association of State Universities and Land Grant Colleges and U.S. Department of Agriculture. This study estimates private R & D as 53.9 percent of total R & D in Agriculture in 1965. P. 52.

4/ See for example the "Annual Reports on the Agricultural Experiment Stations".

5/ This is true as long as the measurement of inputs do not reflect fully their improved quality.

6/ Source: "Report on the Agricultural Experiment Stations" and Latimer, R. 6. [5].

Footnotes

7/ For a historical account of experiment station research during this period see, A. C. True [9].

8/ This method of computing a rate of return to research is first used by Griliches in his hybrid corn study [3].

9/ It is somewhat arbitrary as to how far we take research expenditures back. By stopping at 1910 we implicitly write-off the 1890-1909 research as a bad investment and start over with 1910. It becomes a little absurd to go way back to 1890. Using the 10 percent rate of discount each dollar spent in 1890 accumulates to 1268 dollars in 1966, or the public research of 2.7 million in 1890 amounts to about 3424 million in 1966, which is almost 8 times the 1961 level of public research. As it is each dollar in 1910 accumulates to over 188 dollars in 1966. We go back to 1910 mainly to make the results comparable to Schultz's original estimates, which assumes the investment period as extending from 1910.

10/ The relationship is $B/C = (\frac{PR + AFR/k}{RC})$ where PR is cumulated past returns, AFR is average future returns, k is the rate of discount, and RC is cumulated research costs.

11/ Other independent variables in this model are weather and education. P. 62.

12/ I have benefited from correspondence with Professor Tweeten regarding the details of this technique. The per capita income figures presented here are revised estimates from the 1968 Farm Income Situation which accounts for the slight difference in results from those reported in the article.

13/ In the original article the formula is $K P_1 Q_1 [1 + \frac{1}{2} K n]$. This error is corrected in a reprint of the article in Agriculture in Economic Development. Carl K. Eicher and Lawrence W. Witt, Editors. McGraw-Hill (1964).

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