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ECONOMIC ASPECTS OF THE ORGANIZATION OF AGRICULTURAL RESEARCH

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ECONOMIC ASPECTS OF THE ORGANIZATION OF AGRICULTURAL RESEARCH

Robert Evenson*

The State Agricultural Experiment Stations in the United States differ substantially in size and other organizational aspects. Typically, a close relationship with a College of Agriculture exists, but these relationships vary considerably in terms of the degree of isolation that exists between the researcher and the College. Research conducted by the USDA, on the other hand, is almost completely isolated from the Colleges and Universities. The economics of resource allocation to research includes not only the decisions regarding how much research to conduct and which objectives are to be sought, but under which organizational arrangement the research will be most efficiently conducted. This paper explores the latter issue. The plan of the paper will be to first discuss the research process in a general sense in an attempt to isolate those features which are most relevant to research organization. Empirical evidence will then be presented in support of several general hypotheses regarding organizational features of the agricultural experiment stations.

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* A paper prepared for the Symposium on Resource Allocation in Agricultural Research, University of Minnesota, Minneapolis, Minnesota, February 23-25, 1969. The author, an assistant professor of agricultural economics and economics at the University, is on leave as a visiting assistant professor of economics at Southern Methodist University during 1968-69. I have had the benefit of comments from Zvi Griliches, Finis Welch and T. W. Schultz in the preparation of this paper.

The Research Process

It is probably fair to say that a complete theoretical model of the economics of the research process does not exist at this time. However, a number of studies have provided knowledge of at least some of the economic dimensions. Professor Schultz, in his symposium paper "Resource Allocation in Agriculture," documents and summarizes these studies. My purpose in attempting to describe and catalogue the elements in the research process is to provide a basis for the development of meaningful hypothesis about the expected productivity of research effort pursued under differing organizational arrangements.

In this discussion I will treat the research process as a production process. Such a treatment will necessarily involve a number of dimensions not ordinarily important in the conventional production process. The treatment does allow the use of conventional terminology and related theory. For example, if we can specify the inputs and outputs in the research process, the concepts of demand for outputs and derived demand for inputs can be applied. (It should be noted, however, that these theoretical concepts assume technical efficiency in the production process, a condition which may not be fulfilled in the research process.)

We turn first to a specification of the output or product of the total agricultural research (and extension) effort. A distinction must first be made between "final" products of the process and what might be termed "intermediate" products. The final products may be listed as follows:

(1) Improvements in tangible material inputs (as conventionally understood) used in producing agricultural products.

(2) Improvements in entrepreneurial "allocative decisions" associated with the non-routineness of production.[1/]

(3) Improvements in entrepreneurial "allocative" decisions associated with the adoption of "new" material inputs (which are not necessarily improved inputs).

(4) Improved worker techniques.

(5) Improved agricultural product characteristics.

This list may be modified by others preferring somewhat different terminology. For example, the development of a new technique which does not involve new material inputs, such as improved fertilizer placement or an improved tillage practice is here construed to be incorporated in the third and fourth products on the list. Since improved product characteristics are not a dominant feature of the agricultural research product, and since it is often possible to express, via market information, new products in the same unit as old products, we can gain much in simplification by not dealing directly with it.[2/]

We now turn to the process by which these final outputs are created. The role of the intermediate output will become evident as we do so. It should first be noted that the production of new tangible inputs, such as a new seed, a new machine, or a new chemical, is more direct than the production of the second, third, and fourth products on the list. Strictly speaking, the research and extension effort does not produce improved allocative decisions or worker techniques directly. It simply

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1/The term allocative decisions is used in the same sense that Finis Welch uses the term in his "Education in Production" Paper /11/.

2/If we were treating industrial research, we could not avoid dealing with this difficult area so easily, since it is much more important in that activity.

produces the elements of information that enter into the entrepreneur's decisions. The capacity or the ability of the entrepreneur to interpret and decode the information from the experiment station and other sources is clearly important to this process.[3]

In a similar way, worker techniques are improved as the agricultural worker learns from information that he receives and from his own experience in using new material inputs. The human capital of the producing entrepreneur (defined to be knowledge of a set of relevant facts and an ability to understand and analyze new information) is accordingly very important to the realized output of the research process. It should be noted that the simpler and more reliable an item of information produced by research is, the more rapidly it will be incorporated into an improved decision.

It is also important to note that certain items of information are inherently simple and are neutral with respect to further creation of entrepreneurial human capital. This would be true of simple price or weather data. Other items of information are more complex in that they are sets of related facts, rules or prescriptions for decision-making, or analytic methods or models. These latter items create entrepreneurial human capital as they are learned and incorporated into decisions.[4]

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[3] Finis Welch [11] has argued that the role of education in the development of this ability is one of the most important features of the productive value of education.

[4] With the exception of the treatment of "on-the-job" training this aspect of human capital creation is seldom explicitly recognized in the literature. Generally the human capital formed in connection with formal education is deemed to constitute the bulk of the

Extension activity is designed to facilitate the transfer of the information produced by the researcher to the entrepreneur. Successful extension activity involves simplifying information and attesting to its reliability. In this sense it differs only in degree from research which also seeks to provide simpler and more reliable information. Private firms producing and selling new material inputs to farmers also produce similar information usually related to their own products. Since these firms are acting in their own self-interest and maximizing profits, it is often assumed that the reliability of the information that they generate and extend is always subject to question. As a result, a considerable amount of effort in the public experiment station is devoted to testing the reliability of the information put forth by private firms.[5]

Much research effort is not devoted to the production or creation of these final products but rather to the development of new increments to knowledge which can be thought of as intermediate products inasmuch as they are inputs in the production of the final research products. In the research process the researcher acts in some ways like the

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4/ continued
entrepreneur's or the worker's human capital throughout his lifetime. I am suggesting here that a process of depreciation and investment is continually taking place and that for many entrepreneurs, formal education may bear little relation to the human capital possessed in some later periods. The income-education relationship which has been well established does not disprove this assertion.

5/My impression is that some of this effort (feeding trials, hybrid corn yield tests, etc.) is not especially productive because of the difficulty involved with widely varying local soil and climate conditions. Furthermore, in most instances, it is in the long-run interests of the private firm to provide reliable information.

entrepreneur who is making a decision. The scientist in a general sense is in possession of a certain amount of information, both simple and complex, at any point in time (his human or intellectual capital). His approach to a research problem involves the application of such knowledge as he has and the searching for an interpretation of other information. His methodology conforms in most cases to the scientific method of hypotheses formulation and verification by experimental or statistical methods. Hypotheses formulation is a creative act and the researcher draws on his knowledge and on other information as he approaches a particular problem. Hypothesis verification involves experimental and statistical methodology, and likewise is creative. The concept of "invention" as an act of creating new concepts or new materials is appropriate to this effort. In some cases, the term "search" might be more appropriate to a "trial and error" approach to a research problem. Not all research involves both hypothesis formulation and verification. In fact, much of it is concerned only with the verification of existing hypotheses.

Most research efforts yield some kind of new knowledge. The economic value of this research output is determined by the extent to which as a final product it is an improvement over existing production inputs, techniques, and products. The value of the intermediate research product is determined by the extent to which it is incorporated as an input into other research products and eventually yields a final research product.

One could in principle trace the knowledge development incorporated in a final research product and identify the relevant intermediate research products. A "chain" of knowledge production could be identified in which the knowledge (either possessed by the researcher or sought from other sources) incorporated into the production of the final research product would be defined as the highest level intermediate research product. This intermediate level research product, in turn, would have incorporated the next lower level intermediate product. One could thus define as many levels or stages as are relevant to a given final research product. The lowest relevant level or stage could be defined to be the level where knowledge is no longer specialized in any sense, but part of the general knowledge widely held by educated people.

This "chain" is not chronological in that the elements of knowledge incorporated in the production of final research products were not all produced after the elements incorporated in the highest level intermediate product. In fact, many elements are common to the production of both. Each intermediate product relevant to a higher stage product (where production of the final product is the highest stage) will have been produced earlier, however.

In addition, the output at any intermediate level will be relevant to one or more higher level production processes. For example, one of the most obvious intermediate research products is the development of hypothesis testing methodology, such as statistical techniques and experimental design methods. This kind of intermediate research product is relevant to a great many final research product efforts.

As we have noted already, the result of any given research effort, at whatever level, is subject to uncertainty. We could not specify an "engineering" production function to relate inputs to output because some research effort results in little product of any value. For that matter, the value of a given research contribution is not always known for some time. This does not mean that a relationship does not exist between research inputs and "expected" output.

The talent and motivation of the researcher very much determines the nature of the stages suggested here. With some problems, a single stage may be the only interesting stage. The researcher may be working on a simple problem attempting to produce some final product (such as information) and utilizing only general knowledge in his effort. On the other hand, he may be attempting to produce a final product which involves the incorporation of substantial specialized knowledge, or intermediate research products in his effort and in fact produces not only a final research product but other intermediate products as well. Any attempt to categorize the work of the latter as "basic" or "applied" would be arbitrary.

Nonetheless, research institutions have seen fit to develop specializations or divisions of labor that are based on the level of the research product. Many academic departments and many researchers would insist that they have no interest in turning out final products. This activity is for the "applied" departments. No doubt some of these specializations make sense from an efficiency point of view even though there is little evidence on which to make comparisons of the relative economic value of final and intermediate research products.

The several stage process outlined in these general terms is really centered around the concept of "demand" responsiveness (it could be called a supply response to changes in demand) of research. An economist is perhaps strongly inclined to accept the assumption that research entrepreneurs and researchers themselves are responsive to the demand for their products. This is easiest to see at the final research product level. It is less direct at the intermediate product level since this is a derived demand and since an intermediate research product may be relevant to the production of many final products. There are many ways in which this research can be responsive to derived demand. Contact with researchers producing final products can serve to transmit the demand signals. The professional organizations are important in establishing standards for publication and in a general way for guiding the direction of research.[6/]

Advocates of increased support for "basic" research sometimes defend it in terms of a supply responsive research system. That is, the production of an intermediate research product inspires the research at a higher level which incorporates the intermediate product. No doubt only a small portion of the research which incorporates the intermediate product will be instigated by it. The "supply responsiveness" of research which comes from a "percolating" of signals upward through the research levels is important in terms of information exchange facilitation.

The research products, both intermediate and final, have special properties not possessed by conventional products. The use of a research product in one situation does not preclude its use in another.

6/The work of the late Jacob Schmookler /10/ documents the demand responsiveness of inventive activity in research culminating in a patented product.

It is not used up. This does not mean that it is costless to use it in every relevant situation. In fact, some of the final products of research (information) and the extension activities are required to extend the use of other final products (such as new material inputs) to entrepreneurs. Likewise, the use of intermediate products in every relevant higher level research effort is not costless to obtain.

It is sometimes assumed that the products of research do not depreciate since once something is known that knowledge will be preserved. This is not the case, however, for both depreciation and obsolescence prevail. True depreciation characterizes biologically-based research output. This is typified by the new variety of wheat which becomes subject to new diseases with a resultant loss of yield. Animal and poultry diseases can create the same result. There is a second sense in which depreciation can take place. Our discussion of research has indicated that the intellectual capital of the researcher is clearly an important factor in research. This intellectual capital is subject to depreciation as well as obsolescence. For both reasons a substantial amount of maintenance investment in human capital must be undertaken by researchers in every field.[7/] Specialization can offset this depreciation process to a certain extent, but is not a perfect substitute for continued maintenance investment.

Obsolescence occurs in all aspects of the research process. This is especially true for the final research products. The production of an

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[7/]Of course, from a social point of view the need to educate the new researcher on a continuing basis is in part a maintenance investment.

improved final product which caused an earlier product to become obsolete, does not imply depreciation of knowledge insofar as the knowledge embodied in the earlier product, was incorporated in the improved product.

A final feature that we would expect to hold in the research production process is diminishing marginal productivity. Formally we would define this to mean that holding constant the available and relevant intermediate level research knowledge, increased research effort in a higher order research stage will yield diminishing increments of research product. This abstracts from the uncertainty feature of research, of course. For practical purposes this also calls for holding constant the ability of the researcher as well.[8/] This property of research is very important since it can explain why substantial research effort fails to yield results under certain circumstances. Agricultural research in the less developed economies may have been unproductive for this reason.[9/]

When the target product for a research effort changes, it may open up new possibilities for research advances since new intermediate research products may become relevant. The decline in fertilizer prices, for example, has induced a shift in the target product in crop breeding

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[8/] For direct evidence on the diminishing productivity of research see the author's paper on International Transmission of Sugar Cane Technology /1/ This paper reports the results of the cane breeding program of the Barbados, West Indies, sugar cane experiment station. During the 1930's the station was phasing out its noble cane breeding research and introducing a new breeding methodology, the nobilization method. Using the same testing methods, the new breeding program yielded one new commercial variety per 2500 seedlings brought to the field testing stage. The ratio for the old method was one in 13,000.

[9/] See Professor Schultz's paper for a discussion of this, especially his discussion of agricultural research in India.

research. Breeding for fertilizer responsiveness and related characteristics has been productive because different knowledge has become relevant.

This discourse on the research process has touched on a number of points relevant to the organization of research effort in agriculture. Perhaps the most important has to do with the research methodology. It was noted that the researcher has a stock of intellectual capital and that he seeks additional information in the research process. Those organizational features which make additional information more accessible should be important to research effort in both the short and long run. In the longer run, because of the depreciation of intellectual capital, those organizational features which stimulate investment and intellectual capital are important.

The dominant organizational features are likely to be scale, product mix, and communication facilitating features. The stock of intellectual capital, i.e., the quality of the researchers, is important also in that the higher the level of intellectual capital of one's colleagues, the more accessible is the relevant information sought by a researcher. In the short run, this can be independent of the scale of the experiment station, given that it has freedom to employ researchers without regard to its size.

Scale and product mix are related in the experiment stations in that the smaller stations are likely to be producing a relatively higher proportion of final to intermediate products. They are also likely to be producing relatively fewer new material inputs than the larger station.

The larger stations, of course, have a much wider range of research activity and the possibility of information exchange is much greater.

The specialization of research effort as reflected in the departmental organization and professionalization of specific fields serves both to further and hinder the information exchange between researchers. It increases information exchange by providing a basis within departments for seminars, and intellectual discourse. However, it hinders interdepartmental exchange. The development of specialization along final product (agronomy) and intermediate product (genetics) lines without provision for information exchange between departments is likely to hamper the productivity of all departmental research.

The organizational feature which appears most likely to foster information exchange within departments and certainly between them is the existence of a strong graduate program. This is also likely to be the most important feature which encourages the continued investment in the intellectual capital of the research staff. The need to develop a strong graduate teaching program forces a certain amount of intellectual capital investment that might not otherwise take place. Graduate students serve to challenge the faculty and to bring in new ideas. In fact, for most of the agricultural sciences they are the chief carriers of information from the intermediate product disciplines (genetics, molecular biology, statistics, economics, chemistry, etc.).

All of these organizational features, in effect, argue for more efficient or more productive research. The larger the station, the larger the graduate program and the more favorable the conditions for information exchange.

Empirical Evidence

A simple aggregate production function model was specified as the basic framework in which to measure research productivity. The model is more fully specified elsewhere /2/ and only the major features need be summarized here. The ordinary aggregate production function:

$$O = f(X_1, X_2 \ldots X_n)$$

where the output and inputs are conventionally measured is inadequate for explaining changes in output over time. A recent paper by Griliches and Jorgenson /7/ examines the issues associated with growth accounting and formulates alternative measures to account for the growth in output.

For our purposes we can abstract from most of the problems of growth accounting and concentrate on the expected effect of research output. Since the research products of the public experiment stations are made available at low or zero cost to farmers, we would not expect input prices to reflect them in general. The research products of the private firms producing and selling inputs to farmers would be partially captured in the input price measures.[10/] In general, the same thing would be true for the non-material research products and the associated extension effort.

[10/]They would not be fully captured since farmers would be indifferent to the new inputs if the price of the new inputs reflected the full production value of the input improvement. Some inducement in the form of a lower price will be offered to gain adoption. Also, a given new input may be made obsolete by a competitor's new input at a later time forcing a lower price.

As a conceptual aid we may write the production function as:

$$O = f(X_1Q_1, X_2Q_2, \dots X_nQ_n)$$

where the Q_i are indexes which adjust the measured inputs X_i for quality changes due to the output of the research of the experiment station. Then

$$Q_1, Q_2 \dots Q_n = f(Z)$$

That is, these quality indexes are functions of research resources or inputs Z. If we aggregate the general quality indexes and express this relationship in terms of the relevant time dimensions we have

$$Q_t = f(Z_t, Z_{t-1}, \dots Z_{t-n})$$

or alternatively,

$$Q_t = W(L) Z_t$$

where W (L) is a lag operator specifying the weights in the lag function. This is one specification of the relationship between research inputs and output, the research production function if you like.

A more realistic specification would be

$$Q_t = W(L) G(L) F(L) Z_t,$$

a "convolution" of several lags where W (L) is the lag between expenditures on research and the production of research products; G (L) is the lag between the production of research product and the incorporation of the research product into actual production functions (adoption). This lag is clearly a function of product mix and extension activity. F (L) is the lag effect of depreciation and obsolescence.[11/]

[11/] See Jorgenson [6] for a discussion of the lag concepts.

A stochastic term, itself a convoluted lag function of stochastic terms, would have to be included because of the uncertainty element in research production, as well as for statistical specification. The validity of the relationship between research inputs and output can be implicitly tested by substituting the convolution of lagged research expenditures in the production function and estimating a coefficient for this variable.[12/]

The basic empirical methodology utilized to test this relationship and derive estimates of the marginal product of the research dollar was to search among alternative variables, each constructed from lagged research expenditures, to estimate the mean lag. An "inverted V" form was imposed on the weights in the lag function and the weights were constrained to sum to one. Searching for the variable which results in the highest R^2 in the equation (the variables were tested either by including them in a Cobb-Douglas production function or using a geometrically weighted productivity as output-per unit-input index as the dependent variable) is essentially a non-linear least squares estimation procedure. That variable which results in the highest R^2 (the variables differ only in the number of lagged years included in their construction) yields an estimate of the mean time lag and of the marginal product of the research dollar.

[12/] For a more complete development of the model along with a discussion of the specific lags, see the author's dissertation /3/.

Alternative estimates of the average lag were made utilizing the technique suggested by Jorgenson for estimating rational lags.[13/] The estimated average lags were approximately the same as with the inverted V estimates. The inverted V estimates were more stable between regions and over time. Average lags were estimated for all of U.S. agriculture for several time periods and for each of the ten production regions for the 1939-61 period. The estimated average lags and marginal products of research for the ten regions are presented in table 2 (p.26).

Cross-section data are not very "robust" for estimating the average lag, but do allow some testing of differential marginal products of research from experiment stations with different characteristics. Research and research plus extension variables were constructed from lagged data, using the regional lag form estimates, for thirty-nine states for the years 1954 and 1959.[14/]

Cross-section estimation of research productivity presents several problems not encountered in the time series data. The first is pervasiveness or the tendency for research products produced in one state to be

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13/See Jorgenson Dale, "Rational Distributed Lag Function," Econometrica, Vol. XXXIV, No. 1 (1966). Griliches /3/ presents a discussion of this and other methods in his "Distributed Lags: A Survey," Econometrica, Vol. XXXVI, No. 1 (1968).

14/The basic output and input data are the same as those reported in Griliches Zvi, "Research Expenditures, Education, and the Aggregate Production Function," American Economic Review, Vol. LIV (December 1964), /4/. A detailed explanation of the construction of these variables is included in that source. Some combination of states was necessary because of limited wage data. The New England States; Del., Maryland, Utah, Wy., Nev.; and Arizona, N. Mex. were grouped.

quickly incorporated into farm production functions in other states. If this is serious enough, it would, of course, prevent estimation of research productivity. The fact that estimation is possible does not indicate that the problem does not exist, only that it does not appear to be too serious. One would expect pervasiveness to be greater for intermediate research products than for final products because of professional information exchange activity. If so, it will bias the estimated productivity of the groups of stations with the highest ratio of intermediate to final product downward.[15/]

Another problem is caused by the possibility that differential research productivity, if expected or reflected in rates growth in agricultural output will be capitalized into land values. To minimize this problem, the land measure is based on land classes valued in 1940 relative prices. At that time little capitalization of research productivity should have taken place.

It should be noted that an important adjustment for labor quality was made in the data. An index based on years of school completed by rural residents weighted by national income by schooling class data was used to adjust the labor variable.[16/] The experiment stations were grouped into classes as follows:

15/Latimer and Paarlberg /8/ have argued the case for pervasiveness strongly. They base their argument on the failure to find a research productivity relationship in a model similar to the one reported here. Apparently enough differences in specification exist to account for this.

16/See Griliches /4/ for details of the construction of the labor quality index.

Ph.D. I, 9 stations associated with graduate programs granting 100 or more Ph.D.'s from 1957-63

Ph.D. II, 9 stations associated with graduate programs granting 50-100 Ph.D.'s from 1957-63

Ph.D. III, 12 stations associated with graduate programs granting 2-50 Ph.D.'s from 1957-63

Ph.D. IV, 9 stations associated with graduate programs granting less than 2 Ph.D.'s from 1957-63

Size I, 11 stations with more than 100 agricultural scientists in 1959

Size II, 9 stations with more than 60-100 agricultural scientists in 1959

Size III, 9 stations with more than 45-59 agricultural scientists in 1959

Size IV, 10 stations with less than 45 agricultural scientists in 1959

AAUP I, 9 stations at universities receiving a rank of A or B by the AAUP for salary level in 1960

AAUP II, 18 stations at universities receiving a rank of C by the AAUP for salary level in 1960

AAUP III, 12 stations at universities receiving a rank of D or less by the AAUp for salary level in 1960

Ratio I, 8 stations with a ratio of faculty holding the Ph.D. degree to total faculty of .8 or greater in 1959

Ratio II, 11 stations with a ratio of faculty holding the Ph.D. degree to total faculty of .68-.79 in 1959

Ratio III, 11 stations with a ratio of faculty holding the Ph.D. degree to total faculty of .6-.68 in 1959

Ratio IV, 9 stations with a ratio of faculty holding the Ph.D. degree to total faculty of less than .6 in 1959.

For each set of stations defined above a set of "dummy" variables each taking the value "1" for stations within the class and "0" for stations outside the class was defined. Then for each set, the defined dummy variable was multiplied by the research plus extension variable (in logarithms). Thus, the Ph.D. I variable took the value of the log of research plus extension expenditures for the nine stations in that class and zero for all other stations.

Table 1 reports the results of five regressions where the research and extension variables mentioned were included in a Cobb-Douglas production function of conventional inputs. In general, the coefficient estimates for the conventional inputs did not change appreciably as alternative research and extension variables were included in the equations.[17/]

The equations 1-3 a combined research plus extension variable is included. The effect of extension is very similar to the effect of research which produces non-material final products. We would expect extension to be concerned with information simplification and verification (at a somewhat more practical level than research) as well as facilitating information transfer to entrepreneurs. Thus from an empirical point of view it has been preferable to include a combined research and extension variable. The research variables exclude research in home economics,

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[17/]The coefficient and standard errors for the conventional inputs were:

$$\log \text{Output} = \log C + \underset{(.065)}{.400} \text{ Labor (Adj. for Educ.)} + \underset{(.027)}{.121} \log \text{Land} + \underset{(.045)}{.189} \log \text{Machinery} + \underset{(.027)}{.119} \log \text{Fertilizer} + \underset{(.034)}{.372} \log \text{Other Inputs}$$

Table 1.--Cross-section estimates of research and extension marginal products, 1954-59 combined observations for 39 U.S. states

Regression	Dependent variable	Estimated coefficient	Standard error	Output per farm $	Research or research and extension program $	Estimated marginal product per dollar spent on research and extension
	Dependent variables - research plus extension					
1	Ph.D. I	.0548	.0256	10,380	37.00	16.4
	Ph.D. II	.0618	.0226	8,595	45.30	11.7
	Ph.D. III	.0500	.0249	7,452	36.10	10.3
	Ph.D. IV	.0566	.0244	7,166	34.10	11.8
2	Size I	.0659	.0258	9,710	35.56	18.0
	Size II	.0607	.0249	8,718	39.35	13.5
	Size III	.0678	.0244	5,940	32.13	12.5
	Size IV	.0623	.0239	8,750	45.10	12.1
3	Ratio I	.0625	.0235	11,160	57.82	12.1
	Ratio II	.0541	.0244	8,235	34.04	13.1
	Ratio III	.0551	.0235	6,240	33.65	10.2
	Ratio IV	.0584	.0245	8,830	34.17	15.0
	Dependent variables - research only					
4	AAUP I	.0215	.0143	10,400	21.70	10.3
	AAUP II	.0239	.0141	7,920	20.60	9.2
	AAUP III	.0212	.0132	7,338	21.45	7.2
5	Ph.D. I	.069	.027			7.1
	Ph.D. II	.073	.027			6.7
	Ph.D. III	.065	.026			4.5
	Ph.D. IV	.072	.027			6.2
Pervasiveness		.00019	.0001			
log Res. X Ed.		.000018	.000008			

forestry, and utilization of farm products. Likewise an attempt to include only production related extension expenditures has been made. Attempts to include a separate extension variable and estimate a separate coefficient generally were not successful.[18/]

The results of the first three regressions support the hypotheses that the largest stations and the stations with the largest graduate programs yield a higher marginal product per dollar of research than the smaller three classes of stations, or those with smaller graduate programs.

It will be noted that the coefficients do not differ appreciably by class. However, since they are elasticity estimates, the marginal product estimates differ because the ratios of output per farm to research and extnesion per farm differ.[19/] The fact that the differences in the

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[18/]Inclusion of only a research variable leaves the possibility of bias since research is generally highly correlated with extension. The exclusion of a measure of private research activity likewise biases the coefficient upward.

[19/]An approximate test for the difference in the marginal product estimates can be applied. The basic test is developed in J. Johnston, Econometric Methods (New York: McGraw Hill, 1963), p. 132, among other places. Instead of testing for the difference between two coefficients, we wish to test the differences between marginal products. If the marginal product estimates between Class I and 2 were equal,

$$b_1 \frac{\bar{O}_1}{\bar{R}_1} / \frac{\bar{O}_2}{\bar{R}_2} = b_2$$ would hold. A "t" statistic

$$t = \frac{b_1 \left(\frac{\bar{O}_1}{\bar{R}_1} / \frac{\bar{O}_2}{\bar{R}_2}\right) - b_2}{\text{var. } b_1 + \text{var. } b_2 - 2 \text{ cov. } b_1 b_2}$$

productivity estimates may be due in part to a size of farm effect raises some question about their interpretation. A "scale" phenomenon exists in that a given research final product is more valuable, the more units of production over which it is spread. This would imply that a state with larger farms could get higher productivity simply because fewer resources need be devoted to information generation and transfer to speed adoption of new inputs.

The results for the third equation provide no support for the contention that the ratio of faculty holding the Ph.D. degree is related to station productivity. Regression 4 does provide support for a relationship between faculty compensation and productivity.

19/continued
yields an approximate test. It is not exact because the factor $\frac{\bar{O}_1}{\bar{\bar{R}}_1} / \frac{\bar{O}_2}{\bar{\bar{R}}_2}$ is not necessarily a constant. If not, some correction for its variance and covariance should be made. The "t" values reported below should be interpreted in that light.

Ph.D. I - Ph.D. II "t" $= \frac{.01996}{.008331} = 2.4$

Ph.D. I - Ph.D. IV "t" $= \frac{.0166}{.00655} = 2.54$

Size I - Size IV "t" $= \frac{.03143}{.00567} = 5.5$

Size I - Size II "t" $= \frac{.0212}{.0059} = 3.6$

AAUP I - AAUP III "t" $= \frac{.009844}{.004876} = 2.02.$

The fifth regression is reported with some apprehension and should really serve to suggest further research directions more than anything else. It includes two variables not included in the first four regressions. The Pervasiveness variable represents an attempt to test for and control for the pervasiveness of research. It is a weighted average of commodity research intensities. For each major commodity a national research intensity or production research per dollars worth of commodity is calculated.[20/] For each state the intensities were weighted by the share of the commodity in the state's output.

If research productivity were equal in every commodity and if research results were completely pervasive this variable should dominate the state research variable. Variations in state research would not affect agricultural output except as they are reflected in the pervasiveness variable. The fact that the coefficient is 1.9 times its standard error suggests that it is reflecting some pervasiveness. Its inclusion does not alter the coefficients on the research variable greatly (it lowers them somewhat).

The second variable, log Res. X Ed. raises some questions regarding the relationship between research output and the education of the

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20/The research expenditures per dollars worth of commodity produced in 1959 were:

Food and feed grains	.00247	Cattle & calves	.00199
Cotton	.00099	Hogs	.00132
Dairy	.00176	Sheep & lambs	.00639
Poultry	.00244	Sugar crops	.00264
Oil crops	.00104	Tobacco	.00171
Fruits	.00443	Potatoes	.00777
Vegetables	.00281		

farm labor force. The form of the variable yields an estimate of the β coefficient where

$$O = Ax^{\alpha}R^{\gamma} + \beta(Ed)$$

The education variable is the index of weighted years of schooling completed used to adjust the farm labor variable for changing quality.[21/]

The questions arise from the negative sign of the coefficient indicating a higher payoff from research the lower the educational level of the work force.[22/] This is not necessarily what one would expect. However, if we interpret it in light of the final product mix of the research process, it can make sense. We would expect education to enhance the value of the new material input research products. On the other hand, the information, especially the simplification and reliability establishing aspects, are substitutes for education. They could be worth more in a state with lower educational levels.

An independent set of data exists to allow more evidence on these questions. Table 2 presents regional estimates of marginal products and (marginal) rates of return to investment in research as well as estimated

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21/Similar results were obtained when the ratio of college graduates to non-college graduates was used.

22/This appears to be inconsistent with the recent results obtained by Finis Welch /11/ in an analysis of relative wages in U.S. agriculture. His conclusions were that the more rapid the flow of research output in a state, the higher the wage of the college graduate relative to other laborers, (holding constant the relative number of laborers in each class). It is not clear that an inconsistency exists. I am asking a different question, one which depends on the product mix. Higher levels of education can lower the payoff to research, and it can still be true that the more rapid the flow of research products, the higher the payoff to education.

Table 2.--Regional estimate of research and extension marginal products, rates of return and associated data

Region	Estimated marginal product of research (1)	Estimated rate of return to Res. Inv. (percent) (2)	Estimated average length of lag (years) (3)	Average No. Ph.D.'s granted 1957-63 (4)	Average No. researchers in station (5)	Average No. researchers at university (6)	Average faculty compen- sation (7)	Average ratio of Ph.D.'s to faculty (8)
Northeast	13.3	110	3	41	62	296	8,889	.68
Lake States	24.6	91	6	224	123	1,445	9,767	.80
Corn Belt	45.0	152	5	149	105	1,063	9,323	.66
No. Plains	27.2	50	8	16	65	218	7,758	.59
Appalachian	14.9	57	6	22	66	293	8,145	.58
Southeast	18.3	38	9	18	47	397	7,699	.75
Delta	15.7	34	10	23	52	366	7,870	.60
So. Plains	19.0	36	10	60	88	500	7,897	.56
Mountain	10.2	30	8	5	39	212	8,253	.58
Pacific	29.6	180	4	93	161	1,636	10,025	.83
Matrix of simple correlation coefficients								
(1)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1)	1.000							
(2)		1.000						
(3)	-.829		1.000					
(4)	.606	.567	-.389	1.000				
(5)	.629	.805	-.503	.734	1.000			
(6)	.623	.773	-.462	.831	.944	1.000		
(7)	.507	.880	-.769	.782	.846	.891	1.000	
(8)	.326	.638	-.498	.584	.663	.788	.731	1.000

time lags and other data. The estimates of research marginal product, rate of return, and average length of lag were made from separate analysis of time series data for 1939-61 for each region. The methodology used has been previously described (p. 15).[23/]

The simple correlations in table 2 between estimated marginal products and the Ph.D., Size and Compensation variables provide more support for the evidence in table 1. A clear positive relationship exists between productivity and the Ph.D. and Size variables. A less significant relationship exists with the Compensation variable and the Ration variable is weak in this relationship as it was in the earlier reported results. An attempt to discriminate between the effects of size and graduate program with multiple regression analysis failed. A variable, Ph.D.'s per research dollar had a "t" ratio of 2.9 in a simple regression.

The estimated rate of return is an "internal" rate which uses the estimated lag relationship to project the life cycle of the research products. The simple correlations favor the size relationship over the Ph.D.'s granted. The relationship with compensation is strongest.

The time lag estimates are for the convoluted lag which has the three components: W (L), the lag between research expenditures and the production of a final product; G (L), the adoption lag, and F (L), the

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[23/]For a full discussion of the methodology, see Evenson /2/. The productivity indexes used in the regional analysis were provided in Gordon MacEachern, "Regional Projections of Technological Change in American Agriculture to 1980." Unpublished Ph.D. dissertation, Purdue University, 1964 /9/.

depreciation or obsolescence effect. We would expect the W (L) component to be longer the higher the ratio of intermediate to final research products. The adoption lag should be shorter, the more productive research effort is and the more effort devoted to simplifying and improving the reliability of information. The obsolescence effect will also occur earlier, the faster the rate of new final research products produced. The strong negative relationship between length of lag and marginal product indicates that the latter effect is dominating the lag relationship.

Summary and Conclusions

The evidence presented in this paper supports the existence of economies of scale in the present state agricultural experiment station organization. It also supports the contention that a strong graduate program improves the productivity of research conducted in the stations. It has not been possible to gain much evidence to learn what the separate effects of size and graduate programs are. The data also indicate that the research dollar is more productive in the stations with the highest faculty salaries.

We may agree that the evidence could be much stronger and the methodology clearer and no doubt more research is needed. Nonetheless, the weight of this evidence is sufficient to allow some remarks about policy.

First, it should be noted that we have looked at a research system from a long-run perspective. Size and graduate programs are important in stations that have been in operation for a long period of time. It does not follow that a new station, say in a developing country, must stress a graduate program immediately. Perhaps the best strategy would be to stress the intellectual capital being brought to the research problem and attempt to achieve the most productive mix of final and intermediate products. The graduate school is likely to be important in the longer run.

The policy implications for the present U.S. stations are not so clear either. One must admit to some political and other benefits from having a state experiment station even though it may be small. On the question of the small station, especially the branch station, the issue of product mix comes up. The production of new or improved material inputs is central to the productivity of the experiment station. The isolation of the small branch station raises the cost of information transfer between researchers, a point central to the conclusions of this paper, and makes the conduct of research inefficient. It does not follow that the extension worker or the researcher concerned only with simlifying information and testing is inefficient under these conditions. On balance it would appear unlikely that the branch stations can be justified as research organizations.

As to small station policy, some regional and commodity specialization seems worth considering. The implications of the seeming importance of the graduate school raises serious questions about the location of agricultural research apart from a university setting. A number of USDA labs including the Beltsville station may be adversely affected by this lack of contact with other related research departments. The recent advances in the biological sciences raise the possibility of major advances in plant and animal research in the near future. The experiment station without close contact with the biological science fields is not likely to be in the vanguard.

The relationship between education and research suggested in table 1 raises the possibility that the product mix in the experiment stations is not optimal in that too much effort is devoted to those products that are substitutes for education. This may not be a high payoff activity. The penchant of agricultural administrators to curry favor with sources of support by stressing the production of final products has probably resulted in too much extension and education substituting work relative to the production of intermediate products.

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