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THE DECLINING PRODUCTIVITY OF AGRICULTURAL RESEARCH

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Based on the results of numerous evaluations, agricultural research has gained the reputation of being a high payoff investment. Marginal internal rates of return in the neighborhood of 35 to 50% have been frequently reported.1/ While the returns to past investment in agricultural research appear to have been high, we should not use these figures to predict the payoff to current and future investment unless we can be reasonably sure that (1) the agricultural research production function is stable, i.e., does not shift in a stochastic fashion from year to year, and (2) there is no pronounced trend in the productivity of agricultural scientists. The main purpose of this paper is to test these two propositions.

In regard to the stability question, the level of aggregation is crucial. Because of the large amount of uncertainty involved with the research process, we would expect the research production function to be highly unstable or stochastic at the individual project level. On the average, one or two projects out of 10 may produce significant results with the remainder yielding little or no new knowledge. Part of the differences in payoff between projects, may be due to sheer luck, but in large part is likely to be due to differences in the abilities of scientists, particularly in the ability to ask the "right questions."

We would argue therefore that ex ante evaluation of individual projects will not yield reliable results. The returns to the successful projects are likely to be severely underestimated while the returns to the "dry holes" will be grossly exaggerated. Moreover, it may not be evident even after a project is completed and written up whether it is a success, a failure, or something in between. Thus, the stability of a research production function is only a meaningful question when many projects are aggregated. One would expect greater stability moving from the department, to the experiment station, to the national level. We will measure stability at the station level.

Turning to the second hypothesis, one can think of reasons why the productivity of agricultural scientists might have decreased over the past 40 to 50 years, and other reasons why it might not have decreased. But before discussing these reasons, it is necessary to define research productivity. In this paper, we will measure research productivity by the coefficient on the research variable in an aggregate agricultural production function of the Cobb-Douglas form. This is the percentage change in agricultural output for a 1% change in research input. One could also measure research productivity by the VMP of research, or its associated rate of return in constant prices. However, these measures will be influenced by the value of agricultural output relative to research inputs (average product of research), and consequently can be affected by the amount of conventional resources allocated to agricultural production as well as by the productivity of scientists.

Discovery of nature's most accessible secrets by early research inquiries and the subsequent increase in difficulty and cost of producing additional increments to the known stock of knowledge is perhaps the most obvious reason for expecting a decrease in research productivity. If the potential stock of knowledge relating to agriculture is finite and other inputs are held constant, then agricultural research must eventually run into diminishing returns. Of course, no one knows if the potential stock of knowledge if finite. But the main reason why one might not be surprised by at least a constant productivity of scientific effort over the years is the large increase in the stock of knowledge that exists today in comparison to preceding decades. Because of the large increase in the stock of human and nonhuman capital (computers, better microscopes, etc.) the productivity of scientists could conceivably increase.2/

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Although there have been numerous studies which have reported estimates of the production elasticity of research, differences in model specification and data used make it impossible to compare results and to draw conclusions about the stability of the research production function or changes in the productivity of scientific effort over time.[3] In this paper, we will present the results of estimating six aggregate agricultural production functions with agricultural research and extension as separate variables from cross section data covering the census years 1949 through 1974. Major emphasis will be on the size and stability of the research coefficient over time.

I. The Model and Variables

We employ the basic Cobb-Douglas production function that has been used in most production function estimates of the returns to agricultural research.

$$(1) \qquad Q = A \prod_{i=1}^{n} X_i^{\alpha_i} \prod_{\ell=1}^{m} R_\ell^{\beta_\ell} e^{u}$$

where:

Q is the aggregate agricultural output per farm

A is a constant shift factor

X_i are the $i = 1$ to n conventional inputs

R_ℓ are the unconventional inputs, mainly, research and extension expenditures

α_i and β_ℓ are the coefficients of the respective inputs

u is the random error term

A detailed description of the variables, their construction, and data sources is given in the Appendix. We present here a general description of the variables and the motivation underlying their construction. The main objective was to construct the variables in a manner that provided as much comparability as possible over the 25-year period. All the conventional variables and extension are measured on a per-farm basis whereas research is specified on a per-state basis. (We explain below why research is handled differently.) Forty states are included in the analysis.[4]

A. Output

Output is defined as the sum of cash receipts from marketings, value of home consumption, government payments, and net change in inventories. Each of the 12 commodity groups making up the cash receipts from marketing figures was deflated by the corresponding USDA prices received index, 1967 = 100, before aggregating.

B. Conventional Inputs

The conventional inputs include land, labor, machinery, fertilizer, and other inputs. Land and labor are adjusted for quality differences both cross sectionally and over time. Special attention is given to avoiding the capitalization of research benefits into the land variable. Land prices in 1944 are used as weights thereby eliminating any impact of technical change on the price of farmland since that time. As described in the Appendix, we also adjust labor for quality differences between states and over time.

Specification of the machinery variable probably causes more problems than of any other variable in models of this type. The main source of these problems is lack of information on the age of the various types of machinery on farms and how service flow varies with age. For example, old tractors tend to be kept mainly for light work. If these machines are valued at new prices, their service flow would be overstated. On the other hand, if they are valued at their depreciated or current market prices, the result will be to likely understate their service flow.[5] Because of these problems, expenditures on fuel and repairs are used as a proxy for the service flow of farm machinery. Admittedly, this procedure rules out the estimation of the VMP of farm machinery, but the strong likelihood of a high correlation between deflated expenditures on fuel and repairs and the true service flow of farm machinery should lessen the chance of biasing the research coefficient.

C. Weather

Because of differences in weather patterns between years and the possibility that such differences could influence the research coefficient, it is necessary to include a weather variable. Looking at weather in more detail, it is useful to separate the influence of weather into a location and a time effect. The first effect is associated with the geographical location of agricultural production. If long-run weather patterns have not changed appreciably over time, the location effect should be captured in the value of farmland. For example, land in the Corn Belt is in part more valuable than land in the High Plains because the former receives more rain than the latter. The second effect results from year-to-year variability in weather for a given location. While the degree of variability of weather is likely to be reflected in the value of farmland, the specific weather conditions prevailing in any given year will not be reflected by land values. To incorporate the time effect of weather, we include in the production function the USDA index of pasture conditions (as a percent of normal) in August of each of the six years. The variable should reflect mainly the quantity and timing of rainfall during the early part of the growing season, at least in rain-fed agriculture.

D. Research and Extension

Specification of the research and extension variable(s) in previous studies has shown considerable variability. Several aspects are important and require brief consideration here:

1) Should research and extension be combined?

In previous studies, the most common approach has been to add the two variables implying either fixed proportions or perfect substitution between research and extension. The two variables have been specified separately in cases where extension is included in a broader education variable. For the purpose of this study, it seems most reasonable to enter the two separately. The extreme assumptions of fixed proportions and perfect substitutes both seem implausible. And, in line with the objectives of this study, we do not wish to allow any changes in the coefficient on extension to distort the measure of research productivity, and vice versa.

2) Per-farm or per-state research and extension?

Past production function studies have utilized both per-farm and per-state specifications of the research variable. The criteria for selecting one specification over the other would seem to be that of public versus private goods. It seems reasonable to classify the output of publicly funded agricultural research as a public good. In general, the use of the results of this research by one person does not preclude use by others. As a result, the number of farmers in a given state should not have any bearing on the impact of that state's research on agricultural production of a given farm. Moreover, the deflating of total state research by number of farms could distort the measure of research output. For example, halving the number of farms should not double the VMP of research which would occur if research is specified on a per-farm basis. In addition, it has been empirically verified that per-state research is a better explanatory variable than the per-farm measure (Bredahl and Peterson, 1976). For these reasons, we adopt the per-state specification of the research variable.

In the case of extension, one can argue that the output of extension agents is a private good with externalities. In many circumstances the use of an extension agent's time by one farmer does preclude its use by others. While it is easy to think of exceptions to this situation, in general the private good nature of extension seems most applicable for production-oriented extension work. Therefore, we specify extension on a per-farm basis.

3) The appropriate lag structure.

There is no question that a lag exists between the time research money is spent and the results show up as increased production. However, there is less certainty regarding the appropriate form of the lag and its duration. In order to test the sensitivity of the research coefficient to various lag structures, we estimated the production functions with the following research variables: current year expenditure, expenditure in t-6, the average expenditure in t-2 and t-6, and a 14-year constrained second order polynomial lag model. Surprisingly, we found relatively little difference in the size of the research coefficient under the various specifications of the research variable (Davis, 1980b). Therefore, we report the results only for the (t-2 + t-6)/2 specification; it is a simple lag yet fairly realistic. The question of the correct lag appears to be more important for computing rates of return to investment in research because of the discounting phenomenon.

II. The Main Results

Maddala (1977) has argued that for testing whether estimated coefficients have changed between data sets, it is more appropriate to use an F test on the results from the pooled versus unpooled data rather than "t" tests on individual slope dummy coefficients.6/ Moreover, if it is appropriate to pool the data, then the reliability of the coefficients will be improved.

In comparing the results from the six separate regressions with regression from the pooled data, we found that the set of coefficients did in fact change over the 1949-74 period.7/ However, when pooled estimates from shorter subperiods are compared to the individual year results, there is evidence of some stability. Specifically, the set of coefficients from the 1949-59 regressions are not statistically different from each other; the same is true for the 1964-74 period.8/ But there is a significant difference between the set of coefficients of the two subperiods. We present in Table 1 the results of the pooled regressions for each of the two subperiods.

The decline in the size of the research coefficient from .072 to .034 between the 1949-59 and 1964-74 periods is the most significant finding of the study. While there appears to be some stability in the agricultural research production function over 10- to 15-year periods in that the research coefficients are not statistically different within each of the two periods, there is a rather pronounced downward trend in the size of the coefficient during the past 25 to 30 years. A clearer picture of this trend might be obtained from the individual year research coefficients (and standard errors) presented in Table 2. (These figures are from the

Table 1: Pooled Production Function Estimates

Variable	1949-59	1964-74
Constant	-4.697	-2.068
	(.841)	(.526)
Labor x Education	.562	.330
	(.075)	(.056)
Fertilizer	.048	.197
	(.014)	(.025)
Other	.318	.356
	(.036)	(.033)
Machinery	.186	.340
	(.040)	(.045)
Land	.137	.037
	(.024)	(.021)
Weather	.122	.058
	(.044)	(.061)
Research	.072	.034
	(.019)	(.020)
Extension	-.058	-.081
	(.029)	(.024)
Dummy 1954	.118	
	(.033)	
Dummy 1959	.263	
	(.059)	
Dummy 1969		.080
		(.039)
Dummy 1974		.196
		(.031)
$\bar{R}^2$	.977	.975
R.S.S.	1.18947	1.08769

*Figures in parentheses are standard errors.

corresponding individual year regressions presented in Table 1 in pooled form.)

Not only is there a downward trend over the greater part of the period, but the rate of decline accelerates from 1949 to 1969. Moreover, the 1964 through 1974 coefficients are not statistically different from zero at the standard confidence levels. The increase in the size and significance of the 1974 coefficient is noteworthy but one observation does not, of course, indicate a trend.

III. Possible Explanations

The obvious question at this point is, Why has the research coefficient declined over the years? While it is beyond the scope of this study to offer a definitive answer to this question, one can think of a number of possible explanations.

1. Even though we have been careful to measure the inputs in units of constant quality and include all relevant variables, one cannot rule out the possibility that the model is still mis-specified and the coefficient on research is biased. For example, it is not clear if the omission of private R&D as an explicit variable causes a bias. We can be reasonably certain that the prices paid by farmers for purchased inputs contain a return to private R&D, so in this sense private R&D is implicitly included in the production function. If, for some reason, the research coefficient is biased, the question then becomes, Is the bias positive in the early years of the period, negative in the later years, or both? And if the research coefficient is biased, why should it be biased in part of the period and not in the other, or biased in different directions in different years?

2. Research results are becoming more pervasive and as a result it is becoming more and more difficult to capture the impact of experiment station research with cross-section data. For this explanation to carry much weight, one must think of a good reason why research results are becoming more pervasive over time.

3. Immediately after World War II there was a stock of known but unused technology "on the shelf" and by the end of the 1950s this technology had been widely adopted. If so, then the smaller, more recent year coefficients represent the true output of experiment stations.

4. Research productivity is cyclical in nature. As scientists exhaust lines of inquiry, their productivity declines until new breakthroughs occur. Then a new cycle begins.

Table 2: Individual Year Research Coefficients (and standard errors)

Year	Coef.	S. E.
1949	.070	(.034)
1954	.062	(.030)
1959	.044	(.024)
1964	.029	(.032)
1969	.014	(.032)
1974	.039	(.040)

It is possible that the larger coefficient in 1974 represents the start of a new cycle.

5. Agricultural scientists have discovered nature's most accessible secrets and now must devote greater amounts of time and resources to produce additional increments of knowledge.

6. The number of undergraduate students per teaching and research faculty member in colleges of agriculture nearly doubled between 1959 and 1974, growing from about 4.7 students per faculty member in 1959-60 to 8.5 students in 1974-75.9/ If undergraduate teaching is competitive with research as seems reasonable, then research has subsidized teaching by increasing amounts over the period, particularly the 1960s and 1970s. Consequently, the measured amount of resources allocated to research is likely to overstate the true figure by larger and larger amounts over the period. It is possible that the true productivity of research may not have decreased at all.

7. Diseconomies of scale exist in experiment stations. As stations increase in size more of the research time of scientists is taken up by committee assignments and administrative duties resulting in less research output per dollar of expenditure.

8. The unexplained residual from the production function, which is what the research and extension variables are supposed to pick up, may have been caused by disequilibrium in the factor markets. A gap between the VMPs of purchased inputs, mainly chemicals, fertilizer, and machinery, and their respective prices can cause an unexplained residual in the production function. If the per-farm use of these inputs in the early part of the period was largest in the major agricultural states where agricultural research also was highest, we would observe a positive correlation between research and the residual. As farmers increased the use of these inputs and moved closer to equilibrium towards the latter part of the period, the unexplained residual decreased, leaving less for research to explain. A disturbing implication of this argument is that the correlation between state experiment station research and the residual was spurious to the extent that the lower real (quality adjusted) prices of these inputs, or the emergence of completely new inputs such as herbicides and insecticides, mainly were the result of private R&D.

The problem that we face is not a lack of an explanation for the observed decline in the research coefficient but rather one of too many explanations.

Another puzzle is the highly significant negative coefficients on the extension variable. One possible explanation for this result is that the higher the extension expenditures, the closer farmers are to equilibrium, and the smaller is the unexplained residual. Alternatively, it can be argued that states which have allocated relatively more resources to extension than to research have not created as many new disequilibria resulting from new inputs or techniques, and as a result their output is smaller than it would otherwise be.

Clearly, we have much to learn not only about the research production function itself but also about how research results are disseminated and how they affect output.

IV. Average and Marginal Products, and Rates of Return

The declining productivity of scientists as measured by the decrease in the production elasticity of research does not necessarily imply a corresponding decline in the rate of return to investment in research. Conversely, a stable coefficient does not imply a constant VMP or rate of return. Recall that in a Cobb-Douglas production function the marginal product of an input is given by the production elasticity of that input times its average product (units of output per unit of input). Also, because of the lag between research and the resulting output of agricultural products, the VMP of research must be discounted in order to convert it into a rate of return.

In Table 3, we present average and marginal products and marginal internal rates of return to public investment in agricultural research for the six years included in the analysis. To remove the effects of inflation but to allow for changes in relative product prices, the output values were deflated by the WPI before computing the average and marginal products.10/ Over the period, dollars of agricultural output per dollar of research declined by more than one-half, with most of the decline occurring in the 1950s and early 1960s. In more recent years, the downward trend of the average product of research appears to have stopped. Larger reductions in the VMP and rate of return is observed because of the decline in both the coefficient and average product. In spite of the decline, marginal rates of return to investment in agricultural research remain highly attractive--probably more than twice as high as the rate of return to more conventional investment. Of course, we should not lament the decline in rates of return; this is what should happen when more resources are allocated to high payoff investment.

Table 3: Average and Marginal Products, and Marginal Internal Rates of Return to Agricultural Research in the United States*

Year	Average Product	Marginal Product	Rate of Return
1949	$557	$37.87	100%
1954	415	28.10	79
1959	317	21.09	66
1964	267	8.95	37
1969	255	8.58	37
1974	255	8.66	37

*The coefficients for computing each year's VMP were derived from a constrained quadratic polynomial lag model with an inverted 14-year lag. The sum of the partial research coefficients utilized for the 1949-59 period is .068 and .034 for 1964-74. The VMPs and rates of return should be interpreted as the change in the specified year's output resulting from the preceding 14 years of research. Consequently, the average product figures are the mean values of the corresponding 14-year period. See Davis (1980a) for further discussion of this procedure and for alternative methods of calculating rates of return.

Footnotes

1/For literature reviews on the returns to agricultural research, see Peterson (1971), Peterson and Hayami (1977), and Evenson, Waggoner, and Ruttan (1979).

2/The cost of computer services, etc. is included in the research input but new technology has reduced the real cost of these services over the years.

3/A detailed review of past studies revealed a range of research coefficient estimates of -.017 to .097 in aggregate agricultural production functions. See Davis (1979).

4/States excluded are the six New England states plus Delaware and Maryland. In comparison to the rest of the country, agricultural production in these states is relatively small and their agricultural research has shifted towards environmental and consumer issues.

5/Because an old tractor has a smaller number of years of useful life remaining than a new one, its market value (the estimated discounted present value of future return) will be smaller than the newer model even if the current year service flow of the two are the same.

6/The formula for the F test is (Maddala, 1977, pp. 323-324).

$$F = \frac{(RSS - \sum_{L=1}^{N} RSS_i)/(NK - K)}{\sum_{L=1}^{N} RSS_i/(NT - NK)}$$

which has an F distribution with (NK - K) and (NT - NK) degrees of freedom.

where: RSS is the pooled function residual sum of squares.

RSS_i is the i^{th} individual cross-section residual sum of squares.

N is the number of cross-sections pooled.

K is the number of variables.

T is the number of observations in each cross-section.

7/The resulting F value for all six cross-sections is 2.82 with 40 and 192 degrees of freedom, whereas the critical F values are 1.39 and 1.59 at the 5% and 1% levels, respectively.

8/The F statistic for the 1949-59 period is 1.33 and 1.61 for 1964-1974. The critical F values with 16 and 96 degrees of freedom and 1.75 and 2.19 at the 5% and 1% levels respectively.

9/Undergraduate enrollments for 1959-60 and 1974-75 are 33,800 and 81,736, respectively. Number of teaching and research personnel for these years are 7,201 and 9,577, respectively. Undergraduate student enrollment figures are from the National Association of State Universities and Land Grant Colleges, annual convention proceedings, and number of teaching and research personnel in colleges of agriculture are determined by a head count of the personnel listed in Professional Workers in State Agricultural Experiment Stations, USDA Agric. Handbook Series.

10/As explained in section I, the various products making up gross output were deflated by their respective USDA price indexes for the purpose of estimating the production function in order to make the production function a physical relationship between inputs and output. Research expenditures were deflated by the index of professors salaries because the VMP of an input should be calculated from the value of output and the physical quantity of the input.

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Appendix

Output

The 12 commodity groups include meat animals, dairy products, poultry and eggs, other livestock, food grains, feed crops and hay, cotton, tobacco, oil crops, vegetables, fruits, and other miscellaneous commodities. Data on commodity sales, net change in inventories, government payments, and value of home consumption are from various issues of Farm Income Statistics and Farm Income-State Estimates. The price indexes for deflating the commodity groups are from the USDA Annual Price Summary, 1975. To deflate home consumption, government payments, and the change in inventories, a composite price index was constructed for each state for each cross section by weighting the price index for each commodity group by its proportion of the total receipts from marketings. Data on number of farms in each state is taken from the various issues of the Census of Agriculture.

Land

The land variable was constructed by first multiplying the acreage of land in each state in each land category for each of the six years (taken from various issues of the Census of Agriculture) by Hoover's (1961) price weights, where an acre of pasture is given a weight of 1.0. The number of pasture equivalent acres in each state in each year was then multiplied by the 1944 value of an acre of pasture land to obtain a dollar value of land of constant quality between states and over time. This procedure should avoid picking up any capitalization of research benefits into the value of land since 1944.

Labor

To construct labor, we employ the same procedure utilized by Griliches (1964) using data from the various issues of the Census of Agriculture. This gives a measure of total number of farm operator equivalent days worked on farms in each state. The labor variable was then multiplied by an education variable to yield a constant quality labor input between states and over time. The education variable was constructed by multiplying the proportion of the rural farm males over the age of 25 in the various years of schooling completed categories by the corresponding mean income level for each category. The resulting weighted average income figures are proxies for the quality of farm labor in each state. The proportion of males over the age of 25 in each year of schooling category was obtained from the 1960 Population Census while the mean income figures for each schooling category are from Houthakker (1959).

Machinery

As mentioned, expenditures on fuel and repairs are used as a proxy for the service flow of farm machinery. The USDA index of motor supplies was used to deflate repairs while a price index constructed from the prices paid by farmers for diesel fuel was used to deflate the fuel component. (Data sources are the USDA Annual Price Summary (1975) and various issues of Agricultural Statistics.)

Fertilizer

This input is defined as expenditures on fertilizer and lime deflated by the USDA index of fertilizer prices. The expenditure data is from various issues of State Farm Income Statistics, and Farm Income-State Estimates, and the price index is from the USDA Annual Price Summary, 1975. A fertilizer variable made up of the weighted average of plant nutrients, using prices as weights, also was constructed. However, there is considerable variation in relative prices of plant nutrients over the period which makes it difficult to determine the "correct" weights to use. Also the two alternative fertilizer variables gave similar results.

Other Inputs

This category includes feed and livestock purchased, as well as expenditures on seed, repairs to farm structures, and other miscellaneous inputs such as pesticides, medicines, and custom work. Each item was deflated by the appropriate USDA prices paid index before aggregating.

Weather

As mentioned, this is the USDA index of August pasture conditions where "normal" conditions in each state is assigned an index of 100. The index is taken from various issues of Crop Production.

Research

This variable is defined as total expenditures of the state agricultural experiment stations minus expenditures on land and buildings. Data from 1934 to 1961 are from Latimer (1964) and from 1962 onward from the various issues of Funds for Research at State Agricultural Experiment Stations and other Cooperating Institutions. A price index constructed from average salaries of college and university teachers was used to deflate research expenditures (Davis, 1979).

Extension

State extension expenditure figures for 1934 to 1961 are from Latimer (1964) and for the remaining years from unpublished tables circulated to all agricultural experiment stations. The total extension expenditure figures were adjusted to reflect only production oriented extension (adjustment factors from Cline, 1975). The adjustment factors and producer oriented extension are reproduced in Davis (1979). The research price index described above was used to deflate extension.