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The Productivity and Allocation of Research: U.S. Agricultural Experiment Stations

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The evidence forthcoming from a number of studies supports the hypothesis that investment in agricultural research in the United States has paid off with relatively high rates of return (Schultz; Griliches, 1958, 1964; Peterson, 1967; Evenson; Schmitz and Seckler). However, relatively little is known about the efficiency of the allocation of agricultural research. If there are differences in the rates of return to the various kinds of research, then the overall rate of return (for a given level of investment) could be increased by reallocating some research resources from the low to the relatively high return activities.

The main purpose of this paper is to present estimates of the marginal products and rates of return to the four major categories of agricultural research conducted by U.S. agricultural experiment stations (cash grains, poultry, dairy, and livestock).

I. The Model

We utilize aggregate agricultural production functions with research as a separate independent variable to estimate the marginal products of research. The production function approach affords a rigorous test of the effect of research on agricultural output and enables one to compute marginal (as opposed to average) rates of return.

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In general terms, the production function governing the output of each commodity can be specified as follows:

(1) $Y_{it} = f_i(X_{ijt}, R_{it-\ell})$ $(i = 1,\ldots, k;\ j = 1,\ldots, p;\ \ell = 0,\ldots T)$

where:

Y_{it} = output of the ith commodity in year t.

X_{ijt} = jth input in the production of the ith commodity in year t.

$R_{it-\ell}$ = research applicable to the ith commodity in the t-ℓth time period.

The model implies that the marginal productivity of research can be differentiated with respect to time. Hence the following definitions are in order.

1. Accumulated marginal product of research (AMPR):

   The effect of all past and current research on current output.

$$AMPR_{it} = \sum_{\ell=0}^{T} \partial Y_{it}/\partial R_{it-\ell}$$

2. Marginal product of research (MPR):

   The effect of current research on current and future output.

$$MPR_{it} = \sum_{\ell=0}^{T} \partial Y_{it+\ell}/\partial R_{it}$$

3. Short-run marginal product of research (SMPR):

   The effect of current research on current output.

$$SMPR_{it} = \partial Y_{it}/\partial R_{it}$$

The importance of these distinctions is established in the discussion of the empirical model.

An estimated unitary elasticity of substitution between capital and labor allows the use of the standard Cobb-Douglas production function for the empirical model.[1/] The "true" model is specified as:

$$(2) \quad Y_{it} = A_i \prod_{j=1}^{p} X_{ijt}^{\beta_{ij}} \prod_{\ell=0}^{T} R_{t-\ell}^{\gamma_\ell} e^{\varepsilon_{it}}$$

where γ_ℓ, the coefficient on research, varies according to the date of the research input. Moving forward from year "t" we would expect γ to first increase because of a lag in the output and utilization of research but then decrease as current research becomes less related to future technology and also because of the depreciation of knowledge.

The "true" model could be estimated only with time series-cross section data. Unfortunately, such data are not available; we are limited to a single year (1969) cross section. Thus, the estimation model is specified as:

$$(3) \quad Y_i = A_i' \prod_{j=1}^{p} X_{ij}^{b_{ij}} R_i^{\delta} e^{u_i}$$

Because a single year cross sectional model is utilized to estimate the parameters of the "true" model, the consequence of omitting lagged research expenditures should be determined. If we assume that research has been increasing at a constant rate over time such that $R_{t-1} = k R_t$ where $0 < k < 1$, the "true" model can be written as follows:

$$LnY_{it} = LnA_i + \sum_{j=1}^{p} \beta_{ij} LnX_{ij} + \gamma_o LnR_{it} + \gamma_1 LnR_{it} + \cdots + \gamma_\ell \ LnR_{it}$$

$$+ \gamma_1 \ Lnk + \cdots + \gamma_\ell \ Lnk + \varepsilon_i$$

Collecting terms:

$$(4) \quad LnY_{it} = (LnA_i + C) + \sum_{j=1}^{p} \beta_{ij} \, LnX_{ijt} + \sum_{\ell=0}^{T} \gamma_\ell \, Ln \, R_{it} + \varepsilon_i$$

$$\text{where } C = \sum_{\ell=1}^{T} \gamma_\ell \, Lnk \text{ (A constant)}$$

The expected values of the parameters of the estimation model follow:

$$E(Ln\hat{A}_i') = LnA_i + C$$

$$E(\hat{b}_{ij}) = \beta_{ij}$$

$$E(\hat{\delta}) = \sum_{\ell=0}^{T} \gamma_\ell$$

Therefore, utilizing current year research as the research variable biases the expected value of the estimated constant term ($\hat{A}'$) of the production function upward but does not bias the expected value of the estimated coefficients of the conventional inputs (X_{ij}). More important, however, what effect does the misspecification of the model have on the expected value of the estimated marginal product of research?

The expected value of the estimated marginal product of research (evaluated at geometric means) is:

$$E(\partial Y_t/\partial R_t) = E(\hat{\delta}) \cdot (\bar{Y}_t/\bar{R}_t)$$ [2/]

Substituting and expanding yields:

$$E(\partial Y_t/\partial R_t) = \gamma_o(\bar{Y}_t/\bar{R}_t) + \cdots + \gamma_\ell(\bar{Y}_t/\bar{R}_t)$$

This measure is clearly larger than the defined short-run marginal product of research. The relationship to the other definitional measures of the marginal product of research may be determined. (Recalling $R_{t-1} = kR_t$; $k < 1$)

$$AMPR = \gamma_o \left(\frac{\bar{Y}_t}{\bar{R}_t}\right) + \gamma_1 \left(\frac{\bar{Y}_t}{k\bar{R}_t}\right) + \cdots + \gamma_\ell \left(\frac{\bar{Y}_t}{k^\ell \bar{R}_t}\right)$$

The expected value of the estimated marginal product of research is clearly less than the accumulated marginal product of research because each $\bar{R}_t$ after the first term in the AMPR definition is multiplied by a constant which is less than one. The marginal product of research (MPR) in time t is indicated by:

$$MPR = \gamma_o \left(\frac{\bar{Y}_t}{\bar{R}_t}\right) + \gamma_1 \left(\frac{\bar{Y}_{t+1}}{\bar{R}_t}\right) + \cdots + \gamma_\ell \left(\frac{\bar{Y}_{t+\ell}}{\bar{R}_t}\right)$$

The relationship of the expected value of the estimated MPR and the "true" MPR is dependent on the level of future research and conventional input use. To the extent that these figures increase in a manner that increases the average product of research, the estimated value of MPR will under-estimate its "true" value. If so, then the estimated marginal products of research obtained in this study can be regarded as lower bound estimates of the "true" MPR's.

II. The Variables and Data

A. Output. Output is measured as average value of output per farm for each of four types of farms (cash grains, dairy, poultry, and livestock) as reported by the 1969 Census of Agriculture. A farm is included in a "type of farm" classification if over 50 percent of its sales are of a given commodity type. These four farm types account for over 80 percent of all farms and sales of agricultural products in the United States.

A more accurate measure of the relationship between output and its related research may be obtained if the dependent variable in each production function includes only that output which corresponds to the farm classification. For example, any livestock production which may have taken place on cash grain farms is not included in the dependent variable of the cash grains production function and vice versa. Also, constant prices are used to aggregate output in order to remove the effect of inter-state price differences. More specific definitions of the four variables are presented in the appendix.

B. Conventional Inputs. To the extent allowed by the data, the conventional inputs are selected and measured to reflect as close as possible the output included in the dependent variables. For example, the land input in the cash grains function includes only the harvested acreage of the crops included in the output. Of course, for certain inputs it is not possible to apportion their use exactly to the output included. For example, tractors and equipment on cash grain farms no doubt are utilized in the production of other crops such as cotton in the south and west and sugar beets in the midwest and west. In order to obtain unbiased estimates of slope coefficients, an instrumental variable (IV) estimation technique is utilized in addition to ordinary least square (OLS).[3/] Again, inter-state price differences that are not considered to reflect quality differences are removed. Specific definitions of the independent variables and data sources are presented in the appendix.

C. Research. Because production decisions are made at the farm level, the farm is the proper unit of observation for the dependent and conventional independent variables. However, it is not clear that a per farm average is the correct specification for the research variable. Previous

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C. Research. Because production decisions are made at the farm level, the farm is the proper unit of observation for the dependent and conventional independent variables. However, it is not clear that a per farm average is the correct specification for the research variable. Previous studies have utilized both per farm averages (Griliches, 1964; and Evenson) and state totals (Peterson). Dividing total state research by number of farms obtaining a per farm average implies that the number of farms is a proxy for the number of problems faced by scientists; the greater the number of farms the greater the diversity of problems. On the other hand, the use of the state total as the research variable treats research as a public good. In this case, the research variable which can be viewed as a proxy for the output of the experiment station is not altered by the number of farms in the state. For example, halving the number of farms in a state should not double the measured research output of the experiment station. Certainly both specifications of the research variable have some justification. Perhaps the "true" specification lies somewhere between the two. An empirical test can be made, however, to determine which specification comes closest to the truth.

Each of the aggregate production functions estimated in this study may be written as:

$$\Sigma Y/n = A \prod_i (\Sigma X_i/n)^{\beta_i} \cdot (R/n^{\alpha})^{\beta_r}$$

where:

ΣY is the sum of the appropriate output of the particular class of farms in the state.

ΣX_i is the sum of the appropriate conventional inputs.

R is the total appropriate research.

n is the number of farms in the particular class.

If α equals one, then research per farm is the correct specification whereas total state research is correct if α is estimated to be zero. Estimates of α are obtained from the following equation.

$$Ln(\Sigma Y/n) = LnA' + \Sigma b_i Ln(\Sigma X_i/n) + b_r LnR - cLn(n)$$

The estimated coefficient ($\hat{c}$) of the number of farms is an estimate of the product of $\alpha \cdot \beta_r$. Because $\hat{b}_r$ is an estimate of β_r, $\hat{\alpha}$ is easily estimated by dividing $\hat{c}$ by $-\hat{b}_r$, and can be statistically tested for equality to one or zero. Estimates of α for each of the four production functions are presented in table 1.

Table 1. Estimates of (α), the Coefficient on Number of Farms

Cash grains	-.123
Dairy	.301
Poultry	.073
Livestock	-3.720

The estimated value of α is significantly different from one in all four equations and is not significantly different from zero in the first three.[4/] (The relatively large negative value for α in the livestock equation is something of a puzzle.) The results suggest that the research per state is closer to the "true" specification than research per farm. Thus, the former is utilized in all four production functions.

State experiment station research expenditures are obtained from the USDA Inventory of Agricultural Research, F.Y. 1969 and 1970. The composition of each research variable is explained in the appendix.

IV. Regression Results

As mentioned, the possibility of errors-in-variables due to the inability to exactly apportion all inputs to the output measure prompted the use of the instrumental variable (IV) estimation technique to supplement ordinary least squares (OLS). The regression results obtained from the OLS and IV techniques for the four production functions are presented in tables 2A through D.

By and large, the regression coefficients are significant at reasonably high confidence levels. One exception is fertilizer in the cash grains function when the coefficient is restricted to a single value for all observations. This is somewhat unexpected in view of the importance of fertilizer in crop production. However, it should be noted that soybeans and wheat do not receive heavy applications of commercial fertilizer. In cash grains production, corn is by far the major fertilizer user. In order to take account of the diversity of fertilizer use stemming from differences in crops grown, the country is divided into three regions, as shown in table 2A, with slope dummies on the fertilizer variable allowing the coefficient to take on different values for different regions.

Of most interest are the research coefficients. Ranging from .04 for cash grains to .10 for livestock, they bracket the .059 coefficient on all agricultural research obtained by Griliches from 1949-54-59 data (Griliches, 1964). The .061 poultry research coefficient obtained here is virtually identical to the .062 coefficient reported by Peterson from 1959 data (Peterson, 1967).

V. Marginal Products and Rates of Return

A. National Marginal Products of Research. The estimated coefficients of the IV regressions are utilized to compute the marginal products of experiment station research. The research variable is measured as research per state while output is measured as output per farm. Thus, the estimated marginal product of research is measured on a "per farm" basis. To obtain an estimate of "per state" marginal products, the "per farm" estimate is multiplied by the number of farms.

Table 2. Production Functions Estimates

A
Cash Grains

Inputs	OLS	IV
*Fertilizer		
Southeast	.011(0.2)	.038(0.8)
Corn Belt	.111(2.3)	.137(2.8)
Other	.071(1.9)	.102(2.3)
Labor	.234(3.5)	.251(3.2)
Land	.207(2.7)	.192(2.0)
Chemicals	.074(2.1)	.081(1.9)
Seed	.164(2.3)	.132(1.5)
Machinery	.455(3.2)	.447(2.4)
Research	.038(1.5)	.041(1.6)
$\bar{R}^2$	.95	.95
**Sum of coef.	1.18	1.14
41 observations		

B
Dairy

Dairy cattle	.204(3.3)	.177(2.5)
Labor	.548(8.4)	.632(7.9)
Land and buildings	.062(2.8)	.077(2.8)
Pasture	.055(2.3)	.046(1.8)
Feed	.209(4.2)	.151(2.3)
Research	.042(2.7)	.054(2.9)
$\bar{R}^2$	.99	.99
Sum of coef.	1.08	1.08
48 observations		

(continued)

Table 2. (continued)

C
Poultry

Inputs	OLS	IV
Feed	.591(5.4)	.530(4.1)
Poultry purchased	.261(2.6)	.282(2.5)
Land and buildings	.145(4.0)	.123(2.9)
Labor	.163(2.4)	.185(2.3)
Research	.071(1.8)	.061(1.5)
$\bar{R}^2$	.93	.91
Sum of coef.	1.16	1.12
48 observations		

D
Livestock

Feed	.470(4.6)	.547(4.6)
Land and buildings	.290(4.0)	.261(3.3)
Labor	.147(1.2)	.067(.7)
Livestock	.137(1.4)	.137(1.2)
Research	.109(4.2)	.099(3.7)
$\bar{R}^2$	.92	.92
Sum of coef.	1.04	1.01
46 observations		

Figures in parentheses are "t" values.

*The reference dummy is the group of states not included in the southeast and corn belt. The t-values on the fertilizer slope dummies are as follows: OLS--southeast, -3.0; corn belt, 1.9; IV--southeast, -3.1; corn belt, 1.6.

**For cash grains the sum of coefficients is computed from the regression where fertilizer is restricted to a single coefficient for all observations. In all cases the sum of coefficients excludes the research variable.

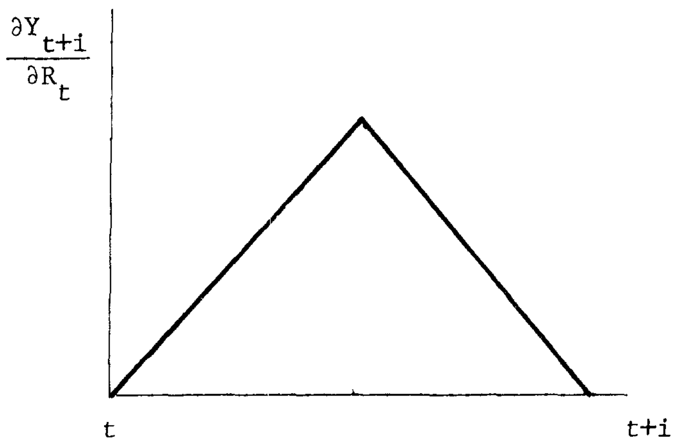
Estimates of national "average" marginal products of research are obtained by using the geometric mean levels of inputs and outputs and the arithmetic average number of farms. The computed marginal product is represented by:

$$\hat{MPR}_i = \hat{b}_{ri} \cdot n_i(\bar{Y}_i/\bar{R}_i)$$

These estimates are given in table 3.

The estimated marginal product of research approximates the "true" marginal product of research; that is, the expected total returns from one dollar invested in 1969. Evenson's work suggests the lag structure of agricultural research resembles that of an inverted "V". The estimated marginal products are approximations of the total area under the inverted "V" in Figure I.

Figure I. Assumed Distribution of Marginal Products of Research Conducted in Year "t"



The calculation of internal rates of return requires that the future returns be discounted. The internal rate of return is approximated by the following:

$$\sum_{i} (\partial Y_{t+i}/\partial R_t)/IRR = 1$$

The calculated internal rates of return are dependent on the mean lag of the lag structure.

According to Evenson's results, the mean lag (high point of the inverted "V") for all agricultural experiment station research is in the neighborhood of 6 to 7 years (Evenson, p. 142). However, estimates of the mean lag of research of the commodity groups of interest in this paper are not available. One might reasonably expect that the lag is somewhat shorter for crops where the possibility exists for large numbers of research trials to be carried on simultaneously than for livestock where biological processes probably constrain the pace of research more severely. For lack of better information, we assume the mean lag to be a bit shorter than average for cash grains, about average for poultry and dairy, and a shade above average for livestock, as shown in column two of table 3.[5/]

Table 3. Marginal Products and Marginal Internal Rates of Return to Experiment Station Research

	Marginal Products ($)	Assumed Lag (years)	IRR(%)
Cash grains	14.09	5	36
Poultry	19.58	6	37
Dairy	25.93	6	43
Livestock	41.76	7	46

In order to arrive at conservative estimates of rates of return, the marginal product figures in table 3 are divided by a factor of three to take account of public extension and private research.[6/] This procedure is likely to bias the estimated rates of return downward for two reasons. First, it is unlikely that research results would go unnoticed in the absence of public extension, or that the extension lags are this long. Really the rate of return to extension should be computed separately on the basis of how much it speeds up the adoption of the new technology.[7/] Second, the cost of private research must already be included in the prices of purchased inputs. Thus, we are in effect double counting the cost of private research. However, it is still necessary to take account of private research because the coefficients on public research probably are picking up the excess of social over private returns to private research.[8/]

If the lags which are specified in table 3 are reasonably accurate, at least in relative terms, the internal rates of return (IRR) of these four major categories of research are not grossly different.[9/] On the basis of this evidence, one might conclude that from a national standpoint, agricultural experiment station research is being allocated fairly efficiently, at least across these four major categories.[10/] Of course, if evidence should come to light which suggests that the cash grains lag is really longer than that specified and/or the livestock lag shorter, then the estimated rates of return would diverge even more. Also, it is evident that the marginal social rates of return to investment in these four categories of research are relatively high, especially in view of the downward biases mentioned above.

B. Across States. In the context of a Cobb-Douglas production function, the marginal product of research depends upon two factors: (1) the coefficient on the research variable (the production elasticity) and (2) the average product of research, i.e., dollars of output per dollar of research.[11/] Experiment stations which exhibit above average productive research workers, and/or because of more dollars of output per dollar of research, will in turn enjoy higher marginal products and rates of return to research than their less productive or smaller average product counterparts.

In order to test for possible differences in the production elasticities of research across states, the sample for each research category is divided into three groups according to the size of their average products of research, with each group having about equal numbers of observations. The same production functions are then run with slope dummies on the research variables allowing the research variable to take on a different value for each group. (The smallest average product states constitute the reference dummy.) The coefficients and t-ratios on the slope dummies are presented in table 4. As shown, none of the slope dummies are significantly different from zero.

Table 4. Research Slope Dummies by Average Product Groups, 1969 (IV estimates)

	Middle Third	Highest Third
Cash grains	.004(.6)*	-.010(-.8)
Poultry	-.008(-.7)	-.009(-.7)
Dairy	.001(.1)	.001(.3)
Livestock	.018(.3)	.021(.9)

*Figures in parentheses are t-ratios.

These results are consistent with the hypothesis that the coefficients on the research variables are not significantly different between comparable departments or between experiment stations. This does not mean that research workers are equally productive across departments or experiment stations. What it may imply is that the market for research workers is functioning rather efficiently. Workers with above average productivity receive above average compensation, and vice versa.

The results presented in table 4 also are consistent with the hypothesis of constant returns to scale of departments, or research areas as denoted by the four categories of research. Except for dairy, the average research for each commodity group per experiment station increases moving from the lowest to the highest average product groups.[12/] If there are economies of scale, then the larger departments or research areas should exhibit larger production elasticities, which they do not.

If the production elasticities of the departments corresponding to the four commodity groups do not differ by size of average product, then differences in average products between states should reflect differences in marginal products and rates of return. Using the research coefficients shown in table 3 (IV estimates), the marginal products of the four research categories for each state are presented in table 5. (These figures are not adjusted for extension and private research.)

It is evident from the marginal product figures in table 5 that substantial differences exist between states in the rates of return to investment in each of the four areas. By and large, the rates of return are highest in those states where the product makes up a large share of the agricultural output of the state and is large relative to the research input. For example, Illinois leads in the marginal product of cash grains research, Arkansas in poultry, Wisconsin in dairy, and Minnesota in livestock.

Also, it appears that some differences exist in the rates of return within states between the four commodity groups, although in this case one should be mindful of possible differences in lags. But when marginal product differences reach the magnitude of 10 to 20 times, it is unlikely that differences in lags can equalize rates of return. Also, there are a number of states where the marginal products are higher for cash grains and poultry which are likely to have the shortest lags. Again within states, the marginal products (and rates of return) for the most part turn out to be the highest for the large and important product categories in each state. For example, livestock research in Kansas appears to have a substantially higher pay-off than poultry research whereas the opposite is true in Arkansas.

The general conclusion that the absolute value of the related output has an important bearing on the rate of return to research is, of course, not new. Griliches demonstrated the importance of the value of related output in his hybrid corn study by comparing the rates of return of hybrid corn research to that of sorghum research (Griliches, 1958). The figures in table 5 just provide a more comprehensive and detailed picture of pay-off matrix.

Of course, the figures in table 5 should be viewed as general orders of magnitude rather than exact, accurate to the penny marginal products. Because the production elasticities are averages over groups of departments or research areas, it certainly would be possible for a given department staffed by very competent and productive people to exhibit an above average production elasticity. Even if such a department were associated with a below average output per dollar of research (average product) its marginal product may equal or exceed a less productive department which enjoys a higher average product. Certainly good judgement and common sense still must be used in research allocation; the figures in table 5 are intended to complement rather than serve as a substitute for good judgement.

Table 5. Marginal Products of Research, the Several Production Functions, by State, 1969.[1/]

State	Production Function			
	Dairy	Cash Grains	Poultry	Livestock
Maine	$ 7.21	n.a.[2/]	$26.97	$ 3.72
New Hampshire	9.80	n.a.	3.40	17.15
Vermont	39.08	n.a.	2.36	2.04
Massachusetts	14.73	n.a.	4.82	n.a.
Rhode Island	2.29	n.a.	1.26	n.a.
Connecticut	18.12	n.a.	13.07	3.39
New York	33.23	1.07	10.21	5.61
New Jersey	8.22	1.87	4.18	3.33
Pennsylvania	24.79	3.64	12.26	3.05
Ohio	15.96	12.52	9.40	15.85
Indiana	12.64	14.60	19.01	32.12
Illinois	9.19	40.14	12.63	38.49
Michigan	11.48	7.32	8.10	11.28
Wisconsin	56.00	2.67	8.41	12.50
Minnesota	51.11	13.15	18.20	75.55
Iowa	16.57	10.62	11.19	60.13
Missouri	8.42	12.30	14.12	53.24
North Dakota	20.27	18.42	2.79	37.24
South Dakota	13.31	6.85	4.18	37.11
Nebraska	4.00	9.45	2.26	28.06
Kansas	6.70	11.25	2.55	52.39
Delaware	2.37	4.21	16.74	2.14
Maryland	8.35	5.00	13.54	5.20
Virginia	10.69	2.57	8.91	9.58
West Virginia	14.24	0.48	8.25	13.08
North Carolina	6.46	3.81	38.71	12.10
South Carolina	7.73	3.84	18.06	6.11
Georgia	5.33	1.92	36.65	14.02
Florida	6.57	1.52	25.22	1.66
Kentucky	15.76	6.20	8.15	16.88
Tennessee	6.33	5.74	17.29	7.23
Alabama	6.14	2.06	48.26	10.39
Mississippi	10.18	8.62	41.01	14.43
Arkansas	4.29	19.83	66.40	8.48
Louisiana	2.58	7.04	6.56	1.88

(continued)

Table 5. (continued)

State	Production Function			
	Dairy	Cash Grains	Poultry	Livestock
Oklahoma	10.51	7.40	10.94	24.26
Texas	30.11	18.91	21.05	43.26
Montana	6.71	13.56	2.82	15.65
Idaho	23.31	6.77	3.38	19.56
Wyoming	2.13	2.36	0.82	11.21
Colorado	41.45	16.73	9.73	61.97
New Mexico	15.26	6.52	3.81	29.37
Arizona	7.38	2.14	5.23	11.01
Utah	7.38	2.12	9.70	13.80
Nevada	3.93	n.a.	1.43	10.18
Washington	11.52	9.88	4.42	9.10
Oregon	7.29	4.60	9.28	8.94
California	20.48	6.17	19.32	18.22

1/ The marginal products of research <u>are</u> <u>not</u> adjusted for private research and extension expenditures. To accomplish this correction each marginal product is divided by 3. Average products may be calculated if the partial production elasticity is known. The partial production elasticities are: dairy -.054, cash grains -.041, poultry -.061, livestock -.071. The average product is derived by dividing the marginal product by the partial production elasticity.

2/ All states with marginal products indicated by the not applicable (n.a.) notation are not included in the sample, i.e., did not have farms classified as cash grain farms, etc.; therefore, estimates of marginal products may not be calculated.

FOOTNOTES

[1]Regressing log V/L = a + b log w where V/L = value added per unit of labor and w = the wage rate per day for hired farm labor (1969 census data) yields a "b" value of 1.126 which is not significantly different from one (Shatova, p. 19).

[2]$\bar{Y}$ and $\bar{R}$ are the geometric means of output and research respectively.

[3]See Durbin, J., pp. 23-32. This technique is of the general form $\hat{b} = (Z'X)^{-1} Z'Y$ where Z is the matrix of instrumental variables, X is the matrix of independent variables, and Y is the column vector of the dependent variable. For each independent variable, the deviates from the mean are calculated and then rank ordered from smallest to largest. The deviates compose the X matrix and the rank ordering the Z matrix. It can be shown that $\hat{b}$ is a consistent estimator of each slope coefficient.

[4]The test is conducted by comparing the error sum of squares from the regressions where it is restricted to one and to zero with the error sum of squares which is obtained when it is unrestricted.

[5]One might argue that dairy and livestock should have about the same mean lag. However, beef, hog, and sheep research which make up the livestock category is somewhat more oriented towards breeding work than is dairy research. Breeding research would seem to have a longer lag than research which bears upon management, such as feeding and health practices.

[6]In recent years extension expenditures have been about equal to research. The magnitude of private research also is believed to be about equal to public research.

7/ For example, see Huffman.

8/ See Peterson (1976).

9/ The internal rate of return (IRR) in this case is that rate of interest which makes the discounted returns of \$1 of research invested in year t equal to the \$1.

10/ Further support of the seemingly efficient allocation of research expenditures may be found by comparing the estimated marginal products of research assuming identical lag structures. In this case equality of marginal products is a sufficient condition for equality of internal rates of return. The variance of the MPR's is approximated by

$$\mathrm{Var}(n_i \cdot \hat{b}_i \cdot \hat{Y}_i/R_i) \simeq n_i^2(\bar{Y}_i/\bar{R}_i)^2 \cdot \mathrm{Var}(\hat{b}_i).$$

These estimated variances may be used to construct confidence intervals of the difference of the difference of any two marginal products (see Miller, p. 67).

$$MPR_i - MPR_j \pm t_{(n-k/1-\alpha/2)} \cdot [\hat{S}^2_{MPR_i} + \hat{S}^2_{MPR_j}]^{1/2}$$

For all pairwise comparisons, the confidence interval contained zero; therefore, the marginal products cannot be judged to be significantly different.

11/ The same holds true for the so-called "index number" approach of evaluating research. In this case, the "k" is comparable to the production elasticity of research and the absolute value of output is comparable to the average product. See Griliches, 1958, and Peterson, 1967.

12/ The average research expenditure per station for each of the four research categories by the three average product groups follow (thousands of dollars).

12/ continued

	Low	Middle	High
Cash grains	258	413	823
Poultry	202	312	409
Dairy	462	417	438
Livestock	514	616	1061

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APPENDIX

The purpose of this appendix is not to explicitly detail the construction of each variable for each production function. Rather, this discussion is intended to present the overall point of view adopted for variable construction and illustrate the techniques utilized. Because the estimated functional relationships are advertised to be aggregate production functions, variables were contructed to reflect variation in physical quantities (free of price variation) rather than total sales or cost measures. Although considerable effort was made to obtain accurate measures of the variables, one should be mindful of possible measurement errors in the data itself.

I. Output. Output measures were constructed to reflect variation in physical quantities produced. The constructed output measures of cash grains and dairy reflect the two general approaches to measure output.

1. Cash Grains = $\Sigma_i Y_i \bar{P}_i$

where:

Y_i ≡ bushels of each type of cash grains produced. (Ag. Census)

$\bar{P}_i$ ≡ national average price of each type of cash grain (Agricultural Prices)

2. Dairy

The first step in measuring dairy output was the construction of an index reflecting price variation.

$$\text{Index}_k = \Sigma_i (S_{ik}/\Sigma_i S_{ik}) \cdot (\bar{P}_i/P_{ik})$$

where:

S_{ik} ≡ sales of ith dairy product in kth state (Agricultural Statistics)

$\bar{P}_i$ ≡ national average price of ith dairy product (Ag. Prices)

P_{ik} ≡ state average price of ith dairy product in kth state (Ag. Prices)

The measured dairy output was constructed via

$$\text{Dairy Output}_k = \text{Sales}_k \cdot \text{Index}_k$$

where: Sales_k ≡ sales of dairy products in kth state (Agricultural Census)

3. Poultry

The output variable is formed in the same manner as Dairy output.

4. Livestock

$$\text{Output}_k = \Sigma_i \text{ Value}_{ik} \cdot \text{No. Sold}_{ik}$$

where:

Value_{ik} ≡ average value of production per animal of ith livestock type in kth state (Ag. Statistics)

No. Sold_{ik} ≡ number of animals sold of each livestock type in kth state (Ag. Census)

II. Inputs

1. Labor. The labor variable for all production functions was constructed in the following manner.

$$L_1 = P_o L_o + P_u L_u + P_h H/W$$

where:

L_1 ≡ calculated man-days of labor used in production of products agreeing with type of farm classification (Ag. Census)

P_o, P_u, P_h ≡ reported proportion of total operator, unpaid (family) and hired labor used in production of products agreeing with the type of farm classification (Ag. Census)

L_o, L_u ≡ total man-days of operator and family labor (Ag. Census)

H ≡ dollars expended for hired and contract labor (Ag. Census)

W ≡ composite wage rate (Farm Labor)

The variation of wage rates was believed to reflect differences in the quality of labor. Hence, the final labor variable was measured by:

$$L_2 = (W_k/\bar{W}) \cdot L_1$$

where:

W_k ≡ kth state average composite wage (Farm Labor)

$\bar{W}$ ≡ national average composite wage (Farm Labor)

2. Land. The land variable is very difficult to measure. For crop production, harvested acres (Ag. Census) was chosen as the appropriate variable. This variable does not reflect variation in land quality. However, the bias of this omitted variable may be determined; the bias resulting from the use of an inappropriate quality adjustment is not known.

Pasture is a direct input into the dairy and livestock production function measured as pastured acres (Ag. Census). For poultry production land serves only as a site of production. The livestock, dairy, and poultry functions must include some measure of capital in the form of buildings. The measure used is:

$$\text{Buildings and Capital}_k = \text{Value}_k \cdot (\bar{L}/L_k)$$

where:

Value_k = market value of land and buildings in kth state (Ag. Census)

$\bar{L}$ ≡ national average per acre value of land (Ag. Statistics)

L_k ≡ kth state average per acre value of land (Ag. Statistics)

5. Research. The research variable is the sum of expenditures for products agreeing with this type of farm classification. For example, the

livestock research variable includes research for sheep, beef, swine and pasture; dairy includes dairy and pasture research. (Inventory of Ag. Research)

6. Other Independent Variables. The other variables are too numerous to detail. Therefore, a very brief description of the other variables in each production function follows.

A. Cash Grains

Fertilizer:	Tons of fertilizer applied adjusted by an index expressing the variation in nutrient content of the fertilizer. (Ag. Census)
Chemicals:	Dollars of agricultural pesticides applied deflated by prices of major pesticides. (Ag. Census & Farmers Pesticide Expenditures)
Seed:	Dollars of seed purchased. (Ag. Census)
Machinery:	The service flow of machinery plus the deflated expenditures for energy sources plus hired machinery and customwork. (Ag. Census)

B. Dairy

Dairy Cattle:	Number of lactating dairy cows adjusted by an index of dairy cow prices. (Ag. Census & Ag. Statistics)
Feed:	Dollars of feed purchased and produced on the farm adjusted for regional price differences. (Ag. Census & Ag. Prices)

C. Poultry

Feed:	Dollars expended for feed adjusted for regional price differences. (Ag. Census & Ag. Prices)

Poultry Purchased: Purchases of poults and chicks adjusted for regional price differences. (Ag. Census & Ag. Prices)

D. Livestock

Feed: Dollars of feed purchased and produced on the farm adjusted for regional price differences. (Ag. Census & Ag. Prices)

Livestock: Service flow of breeding stock weighted by on farm price of each type plus the value of purchased livestock. (Ag. Census & Ag. Prices)