Miscellaneous Publication 8--1981
Minnesota Agricultural Experiment Station
University of Minnesota

Evaluation of Agricultural Research

Proceedings of a Workshop Sponsored by NC-148
Minneapolis, Minnesota May 12-13, 1980

THE PRODUCTIVITY AND ALLOCATION OF RESEARCH: U.S. AGRICULTURAL EXPERIMENT STATIONS, REVISITED

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Estimates of marginal products and rates of return to cash grains, dairy, poultry, and other livestock research in the United States were made by Bredahl and Peterson using 1969 Census of Agriculture data. Their results showed national returns to crop and livestock research to be in the 36 to 46% range. These estimates of returns, several times higher than market rates, have proven useful to agricultural researchers and administrators in supporting budget requests. Bredahl and Peterson provided marginal products by commodity groups by states which have been used by economists in particular states to calculate rates of return to research on commodity groups in those states (Mitchell, Coffey, Babb, and Pratt). More recently, Davis has provided evidence that the production coefficient on the research variable in aggregate agricultural production functions has declined since the 1950s but remained stable for the past 10-15 years. Stability in the aggregate, however, does not necessarily imply stability over time across commodity groups or states. Stability of the research coefficient is an important issue since estimates from studies such as Bredahl and Peterson's are used in making projections of returns to future research spending. Instability over time would indicate that one should not make projections which make use of research coefficients from only one cross-section.

The main focus of this paper, therefore, is to provide additional evidence on the efficiency of allocation of research resources among commodity groups and regions within the United States. Data from the 1969 and 1974 Censuses of Agriculture are employed in aggregate agricultural commodity group production functions to test if the research coefficient for any or all of these groups has remained stable from 1969 to 1974. A second purpose of the study is to examine the effects on the research coefficients of certain variables not tested in the Bredahl and Peterson study. Variables are included to account for research spillover, weather differences, and land quality differences across states. Alternative research lags are tested and the importance of the assumed research lag on the rates of return is also illustrated. The question of research spillover is an important one and has recently received increased attention in the literature (Evenson, White and Havlicek, Davis, Garren and White). It is really the lag in spillover or the incomplete spillover of research results from one state to another that allows one to pick up any variance with a state level research variable in a cross-sectional production function. The spillover that occurs, if unaccounted for, will likely bias the state marginal products derived from commodity group production functions.1/

The Model

The basic model used in the analysis is a familiar cross-sectional Cobb-Douglas production function with conventional inputs specific to individual commodity groups and corresponding research expenditures included as independent variables:

$$(1)\quad Y_t = A \prod_{i=1}^{m} X_{it}^{\beta_{it}} R_{t-j}^{\alpha_{t-j}} S_{t-j}^{\gamma_{t-j}} e^{u}$$

where: Y_t is the value of commodity group output; A, a shift factor; X_{it}, the ith conventional production input in year t; R_{t-j}, the expenditure on research per state in year t-j; S_{t-j}, the expenditure on research in other states affecting each state; β_{it}, the production coefficient of the ith conventional input in year t; α_{t-j}, the production coefficient of research in the t-jth year; γ_{t-j}, the production coefficient of spillover research in the t-jth year; u, a random error term.

Bredahl and Peterson used current (1969) rather than lagged research expenditures as the research variable. While this affected the

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constant term in their equations, they showed that it did not bias the expected value of the estimated input coefficients provided that research has been increasing at a constant rate over time such that $R_{t-1} = KR_t$ when $0 < K < 1$. Other studies have assumed a lag of six to seven years. Davis found that the value of the research coefficient was not sensitive to the specification of the research lag. In this paper, a simple average of research expenditures in 1967-69 was used in most of the estimated production functions. The sensitivity of the research coefficient to lagging the research variable to 1967, 1968, 1969, and 1974 was also tested and is described later in the paper.

The Variables and Data

All variables in the four commodity group functions are measured on a per-farm basis except research and research spillover where state and neighboring state total research expenditures are used to reflect the "public good" nature of research. The major sources of data for nonresearch variables were the 1969 and 1974 Census of Agriculture (U.S. Dept. of Commerce, 1972, 1973, 1977) and unpublished data used by Bredahl and Peterson. Price deflators were obtained from various USDA publications. State experiment station research expenditures were obtained from selected volumes of the Inventory of Agricultural Research (USDA, 1969-70, 1974) and unpublished computer printouts (USDA, 1967, 1968). Specific definitions of the variables can be found in the Appendix. Two of the variables, weather and research spillover, not included in the Bredahl and Peterson study are discussed below.

It is difficult to construct an appropriate weather variable because a combination of crops with varying rainfall and temperature requirements are included in the cash grains group. An attempt was made, however, to capture the effect of deviations from normal weather for a particular location by including deviations from normal July rainfall in that commodity group function.2/ Differences in climate due to difference in location are accounted for in one of the estimated cash grains functions by including dummy variables for different cropping regions.

Bredahl and Peterson mentioned the likelihood of research results from one state spilling over into other states biasing the marginal product. Evenson (1979) and Davis have attempted to account for the spillover in aggregate agricultural production functions by dividing the county up into geoclimatic regions and arriving at subjective proportions of the regional research applicable to each state.

Any approach used to measure the degree of research spillover (including neglecting it entirely) clearly involves arbitrary judgments on how much regional research to include in each state's research total. The problem is compounded because each commodity group is an aggregate of several individual commodities the research for which spills over in different directions and amounts. Soybeans, for example, are very sensitive to day-length and as a result varietal spillover is oriented in an east-west direction. Regional adoption of wheat varieties follows a very different pattern.

The approach taken in the present study to account for research spillovers uses the 16 geoclimatic regions found in Evenson (1979). In most cases, these regions do not follow state boundaries. Research expenditures are prorated among the subregions within each state using its distribution of the commodity group output as a basis. The measured research spillover from state i into neighboring state j consists of the research that occurred in production region k in state i multiplied by the fraction of state j's research which also occurred in production region k. Most states have several of these types of research spill-ins which are then totaled to make up its research variable.

This procedure is admittedly crude and probably underestimates the spillover effects in most cases. It may underestimate the spillover for dairy, poultry, and other livestock more than cash grains because the former is less dependent on climate and soils. The distance over which substantial research borrowing occurs is probably greater for a commodity such as broilers than it is for one such as corn.

Regression Results

The regression results obtained by duplicating Bredahl and Peterson's equations using 1969 data are presented in equation 1 in Tables 1-4.3/4/ Equation 2 in each case represents the same functions estimated with 1974 data. For the most part, the regression coefficients have reasonably large t-values. Of particular interest are the research coefficients which exhibit a wider range for the 1974 data set than for the 1969 data. The research coefficients for cash grains, dairy, and livestock are all slightly larger and more significant than 1969 counterparts. Poultry, on the other hand, is much smaller but no longer significant.

These measured differences between the two sets of equations are not necessarily statistically significant. Therefore, covariance analysis was used to test (1) if each production function as a whole was stable over the period and (2) whether the research coefficient was statistically stable over the period. The estimated regressions in which the 1969 and 1974 data were pooled are shown in equation 3 in Tables 1-4. In each pooled equation the intercepts were allowed to vary to take account of the fact that the lag in the research variable

Table 1. Cash Grain Production Functions*

	(1969) Equation 1	(1974) Equation 2	(Pooled) Equation 3	(Pooled) Equation 4	(1974) Equation 5
1. Land and buildings	.142 (1.59)	.217 (2.20)	.222 (3.64)	.221 (3.59)	.243 (2.38)
2. Labor	.241 (2.90)	.356 (2.41)	.267 (3.94)	.264 (3.88)	.347 (2.34)
3. Chemicals	.089 (2.06)	.011 (.25)	.044 (1.77)	.042 (1.64)	-.001 (-.03)
4. Seed	.11 (1.35)	.196 (2.42)	.195 (4.01)	.202 (3.99)	.216 (.67)
5. Fertilizer	.053 (1.04)	.061 (.64)	.023 (.56)	.021 (.52)	.423 (2.39)
6. Machinery	.540 (3.36)	.476 (2.84)	.469 (4.31)	.468 (4.28)	.105 (3.64)
7. Research (67-69 average)		.091 (3.68)			
8. Research (69)	.073 (2.72)				
9. Research (pooled)			.082 (4.88)	.070 (2.40)	
10. Intercept Dummy for 69 & 74			.295 (4.21)	.077 (.18)	
11. Research Slope Dummy for 69 & 74				.017 (.52)	
12. Research Spillover					-.034 (-.96)
13. Constant	.479 (.76)	-.085 (-.082)	.162 (.32)	.322 (.55)	.504 (.42)
$\bar{R}^2$	.929	.932	.952	.951	

*Numbers in parentheses are t-values.

differed in the 1969 and 1974 data sets. The value of the computed F-ratios for the cash grains, dairy, and poultry equations were above their critical values in the F-table for their corresponding degrees of freedom.5/ This indicates that these data sets should not be pooled because there have been some structural changes over time. The F-ratio for livestock was below its critical value in the table indicating a lack of structural change.

These results do not tell us whether the research coefficient is stable over time but only whether the coefficients as a group are stable for each commodity group. A t-test can be used to test the stability of the research coefficient alone by including a slope dummy on the research variable. Equation 4 in Tables 1-4 shows these results. In all cases, we cannot reject the hypothesis that the research coefficients are the same at the 95% level of significance. In the cash grains, dairy, and livestock cases, this result is not surprising since the coefficients for the two years are of the same magnitude. In the poultry case, the nonsignificance of the research coefficient apparently does not

Table 2. Dairy Production Functions*

	(1969) Equation 1	(1974) Equation 2	(Pooled) Equation 3	(Pooled) Equation 4	(1974) Equation 5
1. Land and buildings	.062 (2.82)	.084 (2.88)	.081 (4.19)	.078 (4.02)	.085 (2.83)
2. Labor	.547 (8.28)	.227 (2.53)	.390 (7.66)	.386 (7.57)	.223 (2.37)
3. Cows	.204 (3.28)	.427 (4.90	.333 (6.04)	.329 (5.97)	.428 (4.85)
4. Feed	.210 (4.17)	.277 (5.25)	.245 (7.78)	.253 (7.78)	.280 (5.04)
5. Pasture	.055 (2.29)	-.041 (-1.50)	.006 (.27)	.008 (.36)	-.040 (-1.50)
6. Research (67-69 Average)		.057 (3.12)			
7. Research (69)	041 (2.62)				
8. Research (Pooled)			.044 (3.68)	.031 (1.89)	
9. Intercept Dummy for 69 & 74			.336 (15.97)	.032 (.12)	
10. Research Slope Dummy for 69 & 74				.024 (1.13)	
11. Research Spillover					.004 (.196)
12. Constant	1.32 (2.95)	5.47 (9.56)	1.80 (4.31)	1.96 (4.44)	2.99 (4.09)
$\bar{R}^2$	.986	.978	.983	.983	.978

*Numbers in parentheses are t-values.

allow us to pick up a statistically significant difference for the two periods.

There are at least two possible explanations for the nonsignificance of the research variable in the 1974 poultry equation. The first is that the spillover of poultry research across state boundaries is very important and that states with a low amount of research have borrowed from neighboring states to the point that their poultry sector is just as productive. It is really the lag in borrowing research from other states, regions, etc., or the incomplete borrowing that allows one to measure a return to research in cross-sectional studies. Also, if the rate of progress in poultry technology has slowed, this would facilitate lower research states catching up with higher research states. Poultry research, in particular, is transferable over a long distance. A second explanation is due to the fact that broilers, turkeys, and eggs are combined in the data set. In some states the proportion of egg production approaches 100% of the poultry output. Egg prices were relatively higher than turkeys in 1974 compared to 1969 so that those states with a higher proportion of egg production experienced a larger percentage increase in value of output than those with a high proportion of turkey output. This could be affecting to some extent the research

Table 3. Poultry Production Functions*

	(1969) Equation 1	(1974) Equation 2	(Pooled) Equation 3	(Pooled) Equation 4	(1974) Equation 5
1. Land	.145 (4.05)	.078 (2.30)	.120 (4.99)	.119 (4.89)	.098 (2.66)
2. Labor	.163 (2.37)	.190 (2.47)	.159 (1.25)	.163 (3.29)	.196 (2.56)
3. Poultry	.261 (2.62)	.180 (2.32)	.214 (3.64)	.226 (3.61)	.175 (2.26)
4. Feed	.591 (5.38)	.700 (7.93)	.668 (10.64)	.653 (9.53)	.702 (8.02)
5. Research (67-69 Average)		.017 (.52)			.022 (.649)
6. Research (69)	.071 (1.84)				
7. Research (Pooled)			.041 (1.77)	.048 (1.81)	
8. Intercept Dummy for 69 & 74			.001 (.014)	.268 (.56)	
9. Research Slope Dummy for 69 & 74				-.021 (-.56)	
10. Research Spillover					.025 (1.31)
11. Constant	-1.09 (-1.79)	-.232 (-.35)	-.786 (-1.89)	-.842 (-1.95)	-.84 (-1.05)
$\bar{R}^2$	.916	.931	.958	.958	.933

*Numbers in parentheses are t-values.

coefficients for 1974.

The results of including a spillover variable in an equation for each of the commodity groups is presented in equation 5 in Tables 1-4. In none of the equations was the spillover variable significant. This result undoubtedly reflects more on the crude nature of the spillover variable specification than it does on the importance of research spillover. Other attempts were made to include a research spillover variable in each commodity group equation but these were also unsuccessful.

The three parts of the poultry output variable were also deflated to remove the price effects from combining poultry, eggs, and turkeys. This affected the equation very little.

A number of other tests were made using the 1974 data for all the commodity groups. The CRIS research data include categories labeled "unclassified" research, "unallotted plant science," and "unallotted animal science." Since these categories are large for some states, research variables were constructed which included a portion of this unclassified and unallotted research. The coefficients on these new research variables differed little from those which did not include the unclassified and unallotted research.

The effect of using lagged versus current research expenditures as the research variable was discussed earlier. Alternative research lags were tested in the 1974 commodity group equations as well as the use of current research, but

Table 4. Livestock Production Functions*

	(1969) Equation 1	(1974) Equation 2	(Pooled) Equation 3	(Pooled) Equation 4	(1974) Equation 5
1. Land and buildings	.129	.042	.126	.115	.068
	(1.53)	(.51)	(2.32)	(2.10)	(.65)
2. Labor	.554	.517	.469	.516	.465
	(1.94)	(2.46)	(2.88)	(3.09)	(2.07)
3. Animals	.136	.057	.114	.100	.068
	(1.16)	(.56)	(1.50)	(1.31)	(.65)
4. Feed	.320	.465	.376	.380	.462
	(2.38)	(5.02)	(4.93)	(4.99)	(-1.95)
5. Research (67-69 Average)		.168			.153
		(6.98)			(4.68)
6. Research (69)	.122				
	(4.69)				
7. Research (Pooled)			.137	.122	
			(8.01)	(5.59)	
8. Intercept Dummy for 69 & 74			.062	-.44	
			(.71)	(-.999)	
9. Research Slope Dummy for 69 & 74				.040	
				(1.16)	
10. Research Spillover					.025
					(.675)
11. Constant	-.455	-.24	-.366	-.237	-.299
	(-.511)	(-.264)	(-.584)	(-.374)	(-.327)
$\bar{R}^2$	.849	.908	.891	.891	.907

* Numbers in parentheses are t-values.

the resulting research coefficients were similar. There was, however, somewhat more variability in the research coefficient in the cash grains equation than in the other commodity group equations.6/

As noted earlier, deviations from normal in July rainfall was also included as a variable in the cash grains function, but the coefficient on that variable was not significant. This is not too surprising in light of the number of different grains included in the cash grains function. Slope dummies on the land variable were included to account for climatic and quality differences in land in the cash grains function, but they were not significant. In this case as well, the aggregation of several grains could be masking the effects of these factors.

The research coefficient was not sensitive to various weighting schemes used on the elements which make up the fertilizer variable. This was tested because previous studies have assumed a variety of weighting schemes and the validity of the one used by Bredahl and Peterson is open to some question.

Marginal Products and Rates of Return

The estimated research coefficients can be used to compute the marginal products of experiment station research. The computed national average marginal product of research for each commodity group is MPR = $\hat{\alpha}\bar{n}\left(\frac{\bar{Y}}{\bar{R}}\right)$ where $\bar{n}$ is the arithmetic average number of farms for that group, $\hat{\alpha}$ the corresponding research coefficient, and $\bar{Y}$ and $\bar{R}$ are the geometric mean levels of per-farm output and per-state research for that group.

The estimated marginal products of research computed with both the '69 and the '74 estimates are presented in Table 6 . 7/8/. These marginal products approximate the long run return from $1 invested in research in either 1969 or 1974.

Table 5. Marginal Products for Experiment Station Research

	Marginal Products (in constant prices)	
	1969	1974
Cash Grains	24	42
Poultry	23	--
Dairy	20	27
Livestock	62	81

In his recent dissertation, Davis points out that previous authors have used varying formulas for computing the internal rate of return (IRR) to research. All have used the general procedure of finding the discount rate which satisfies: discounted (MPR) - 1 = 0. Differences stem, however, from the assumption made about the distribution of benefits over time. The most conservative assumption is that all benefits occur in the "n^{th}" year after the research expenditure. The formula for this is $MPR/(1-r)^n - 1 = 0$, which can be rearranged to $r = (MPR)^{\frac{1}{n}} - 1$, where r is the marginal internal rate of return. As Davis points out, this formula can be very useful for approximation purposes because it is not necessary to use an iterative procedure to calculate the IRR. Bredahl and Peterson made use of the conclusions of Evenson that the best representation of the distribution of benefits over time is that of an inverted V. This can be represented by the shaded area in Figure 1.

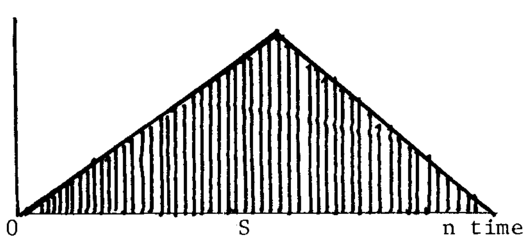

Figure 1.

Davis points out that the following equation can be used to calculate the marginal internal rate of return assuming the lag distribution used by Bredahl Peterson:

$$MPR \left[\sum_{i=1}^{n} \frac{w_i}{(1+r)^i} \right] - 1 = 0$$

where: $w_i = \frac{2i-1}{2S^2}$ For i = 1 to S

$w_i = \frac{2n - (2i-1)}{2S^2}$ For i = S + 1 to n

n = total number of years over which past research has an impact on output.

$S = \frac{n}{2}$ is called the mean lag

r = marginal internal rate of return

MPR = marginal product of research

This formula was used to calculate the IRRs of research to the four commodity groups for both 1969 and 1974 under five different assumptions about the length of the research lag (see Table 6).9/

One of the conclusions that can be drawn from the IRRs in Table 6 is that they have increased over the five-year period for cash grains, livestock, and dairy. This is mostly due to the slightly higher coefficients on the research variable because the average products were deflated to make the marginal products reflect cash grain and livestock prices in 1969. Since the output variable is a price-weighted aggregate for each commodity group, the higher output prices in 1974 otherwise would have increased

Table 6. Internal Rates of Return to Experiment Station Research

	Assumed Mean Lag (Years)	Internal Rate of Return (%)	
		1969	1974
Cash Grains	5	57	85
	6	47	69
	7	40	58
	8	35	50
	9	31	44
Dairy	5	50	62
	6	42	51
	7	35	44
	8	31	38
	9	27	33
Livestock	5	111	132
	6	89	106
	7	75	88
	8	64	75
	9	56	66
Poultry	5	56	--
	6	46	--
	7	39	--
	8	34	--
	9	30	--

the IRRs substantially for 1974. The higher MPs and IRRs are also partly due to the fact that the physical agricultural output was higher relative to research expenditure in 1974 as compared to 1969.

Bredahl and Peterson assumed a five-year lag for cash grains, a six-year lag for poultry and dairy, and a seven-year lag for other livestock. They concluded that the resulting IRRs indicated that agricultural experiment station research is being allocated fairly efficiently across the four categories. The results from Table 6 generally support this conclusion despite the changes made in the '69 data, which were discussed earlier. The livestock return is somewhat higher than the others, however, indicating the largest underinvestment in livestock research. The results for 1974, assuming the same set of lags, would lead one to conclude that returns to cash grains research has increased relative to dairy and other livestock. The results also illustrate very clearly the importance of the mean lag assumed between the time the research occurred and the results are realized. While this lag was shown not to be of great importance in the estimation of the research coefficient, it is extremely important in measuring the IRRs. For example if both cash grains and livestock had the same lag, the cash grains IRR would be below that for livestock for 1974. If livestock had a two year longer lag than cash grains, their IRRs would be about equal for 1974. If cash grains had a lag of five years and livestock a lag of eight years, the return to cash grains research is higher than for livestock in 1974.

Assuming the production elasticities do not differ among states, marginal products of research can be computed for each state for each commodity group by multiplying the research coefficient by the average product of research for each group. Those marginal products are shown in Table 7. They should be taken as very rough approximations since they take no account of the effect of research spillover across state boundaries. They appear to confirm the conclusions of Bredahl and Peterson that there are substantial differences across states for each group and that returns are highest in those states where the product makes up a large share of the agricultural output of the state. If one compares the marginal products in Table 6 with those in the Bredahl and Peterson article, no movement is detected toward an equalization (equilibrium) across states or across commodities within a state.

Conclusions

The research coefficients for cash grains, dairy, and livestock were shown to be statistically stable between the 1969 and 1974 census years while poultry was inconclusive. This lends some support to those studies which use coefficients from past research evaluation studies in *ex ante* projections. This paper also illustrates that the specification of the mean lag between research expenditures and resulting physical output is also quite important for the calculation of the internal rate of return. Finally, the results do not lend support to the belief that returns to agricultural research declined during the early '70s. The results for

Table 7. Marginal Products of Research by Commodity Groups by State, 1974.

State	Cash Grains	Dairy	Livestock
Alabama	8.6	5.23	19.97
Arizona	3.5	8.47	48.07
Arkansas	47.62	5.96	46.13
California	19.42	29.35	55.60
Colorado	51.00	74.01	146.71
Connecticut	.23	7.75	46.70
Delaware	4.88	1.62	14.98
Florida	4.88	12.65	15.46
Georgia	11.01	6.56	26.91
Idaho	27.23	25.89	79.73
Illinois	85.05	6.29	78.51
Indiana	35.75	11.43	53.94
Iowa	33.58	10.39	105.06
Kansas	33.58	6.45	136.47
Kentucky	33.28	14.57	33.79
Louisiana	37.20	3.39	6.46
Maine	16.77	7.27	12.23
Maryland	15.52	7.17	9.73
Massachusetts	.10	11.81	10.62
Michigan	24.75	10.68	32.65
Minnesota	34.15	34.43	166.58
Mississippi	17.36	11.98	39.98
Missouri	36.07	7.33	103.25
Montana	31.96	5.44	35.79
Nebraska	29.26	4.07	73.81
Nevada	1.55	4.30	22.65
New Hampshire	.02	9.21	24.56
New Jersey	5.25	4.46	4.55
New Mexico	12.85	21.50	130.93
New York	3.01	32.23	10.20
North Carolina	13.22	5.73	32.14
North Dakota	41.60	18.46	61.91
Ohio	41.94	17.29	39.66
Oklahoma	22.69	12.97	65.64
Oregon	13.99	8.28	30.56
Pennsylvania	9.55	20.76	37.98
Rhode Island	n.a.	1.85	4.41
South Carolina	10.95	4.92	12.94
South Dakota	20.45	18.28	92.44
Tennessee	18.71	5.75	19.08
Texas	38.99	41.11	197.25
Utah	6.27	8.46	51.71
Vermont	.35	18.27	5.64
Virginia	9.77	15.59	26.59
Washington	18.72	15.61	40.72
West Virginia	2.26	13.89	41.49
Wisconsin	9.59	56.69	30.53
Wyoming	8.94	2.64	37.11

poultry are inconclusive but for other commodity groups the research production coefficients, marginal products, and IRRs have either remained roughly the same or increased. If the 1974 average products were not deflated to 1969 prices, the increases would be even greater.

Footnotes

1/Bredahl and Peterson recognized this and hypothesized that states with the largest departments or research areas are net exporters of research. This would have the effects of biasing the estimated marginal products of the small stations upward and marginal products of the large stations downward.

2/Weather was extremely variable during the summer of 1974. This might be expected to have a small effect on the dairy, poultry, and livestock functions but a more significant effect on cash grains. If good weather prevailed in states with high research expenditures and poor weather in states with low research expenditures this would bias the research coefficient upward. If the opposite occurred, a negative bias would result.

3/The dairy and poultry results are identical to those published by Bredahl and Peterson. Adjustments were made for three states in their cash grains research data and the fertilizer variable was specified differently causing the coefficients on that equation to differ slightly from the one they reported. Their data was not available for the livestock group and therefore, had to be regenerated from their original data sources.

4/Bredahl and Peterson presented instrumental variables as well as OLS estimates but since the differences were small only OLS results are presented in this paper.

5/The test used for homogeneity of slope coefficients was:

$$\frac{V'V - V^{*\prime}V^{*}/K-1}{V^{*\prime}V^{*}/n_1 + n_2 - 2K} = F_{k-1,\ n_1 + n_2 - 2K}$$

where: $V^{*\prime}V^{*}$ = vector of residuals from adding the sums of squared residuals from the 69 and to 74 functions

$V'V$ = vector of residuals from pooled regression

K = number of parameters including constant

n_1 = number of observations in 1969 function

n_2 = number of observations in 1974 function

6/When 1967 and 1968 research expenditures were used as the research variable in cash grains equations the resulting research coefficients were lower than when 1969 and 1974 research variables were used.

7/The average products ($\frac{\overline{Y}}{R}$) have been converted to 1969 dollars to facilitate comparisons between 1969 and 1974 marginal products.

8/A marginal product of research for 1974 for poultry was not calculated due to the nonsignificance of the research coefficient.

9/Following Bredahl and Peterson, to arrive at conservative estimates of rates of return, the marginal product figures in Table 5 were divided by three to take account of public extension and private research before calculating the IRRs.

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Appendix
Variable Definitions for 1974 Commodity Group Production Functions

I. Cash Grains

Variable

1. Output Value of grain sold per farm.
2. Land Harvested cropland per farm.
3. Labor Man-days of operator, unpaid family, and hired labor per farm--Operator - The total man-days of operator labor is determined as follows:

$$L_O = (N_1 + .6N_2)\ .300 - L_1$$

where: L_O = man-days of operator on farm labor

N_1 = number of operators less than 65 years of age

N_2 = number of operators over 65 years of age

L_1 = man-days of off-farm labor

Unpaid family - Data on the hours worked per worker for farm operators, other unpaid family members, and all family workers for four weeks of the year are provided in the USDA publication Farm Labor, February 28, 1975, pages 6-7. These data are used to determine the percentage of farm operator hours which are worked by unpaid family labor. This percentage is then multiplied by the number of farm operators from the 1974 Ag. Census to get the number of unpaid family workers. This is then multiplied by the number of hours per week from the Farm Labor data and then converted to man-days per year.

Hired Labor - The value of hired and contract labor per farm from the census is divided by the state wage rate to get the number of hours of labor. This is then multiplied by 8 to get the number of man-days per year.

4. Seed Value of seed per farm.
5. Fertilizer Data on the tons used, dry and liquid, are found in the 1974 Ag. Census for each state. Data on the tons of N, P, and K applied per state is found in the USDA publication Commercial Fertilizer Annual Consumption for the Year Ended June 30, 1975. This last data is used to determine the amounts of N, P, and K represented by the total tons of fertilizer shown in the census. For example, if N is 40% of the total fertilizer applied in the USDA data, then the tons shown in the census data are multiplied by 40% to get the tons of N applied on the census farms. The value of N, P, and K per farm are aggregated together with weights of 1, 1, and .5, respectively.
6. Chemicals Value of agricultural chemicals (herbicides, insecticides, and fungicides) per farm. The census value for herbicides is deflated by the ratio of the national to the state

price of atrazine. The census value of insecticides is deflated by the ratio of the national to the state price of carbaryl. Fungicides are left undeflated. The three resulting values are added and divided by the number of farms.
7. Machinery Service flow of machinery plus expenditures for energy sources plus hired machinery and custom work - (1) The market value of machinery and equipment is divided by the number of farms multiplied by .15. (2) Data on gasoline, oil, and other petroleum fuels are given on page 1-82 of Vol. I of the 1974 Ag. Census for each state. The gasoline and diesel fuel components are deflated by the ratio of the national to the state price of these fuels. These data are found on page 115 of the USDA publication, Agricultural Prices, 1974.
(3) Data on machine hire and custom work are found on page 1-82 of Vol. I of the 1974 Ag. Census for each state.
8. Research Total expenditure on research--Data are found in the USDA-CRIS publication Inventory of Agricultural Research FY 1969. For each state, the total expenditures for corn, sorghum, wheat, soybeans, barley, oats, rye, and other small grains are totaled.
9. Weather Deviations from normal July precipitation.
10. Soils dummies based on 1957 U.S. Yearbook of Agriculture Geoclimatic Regions.

II. Dairy

Variable

1. Output Value of dairy products sold per farm and dairy type livestock sold per farm. Sales data are multiplied by an index which equals the ratio of the sales of the i^{th} product to total sales times a ratio of the national average to the state average price for the i^{th} product where i = fluid milk sales to plants, direct milk sales, and cream sales. The value of livestock purchased is subtracted from the value of livestock sold and added to the sales figure.
2. Land Value of land and buildings per farm adjusted by the ratio of national average price of land to state average price of land since we are mainly interested in how value of buildings vary.
3. Labor See discussion under "Cash Grains" farms.
4. Feed Value of feed expenditures per farm--Data on dollar value, number of farms, number of tons of each of four feed categories found is found in the Ag. Census. The first category, formula feeds, is adjusted by ratio of national-to-state price of 16% dairy feed. The second category, feed ingredients, is adjusted by ratio of the national-to-state price of soybean meal. The third category, whole grains, is adjusted by the ratio of the national-to-state price of corn. The fourth category, hay, green chop, and silage, is deflated by the ratio of the state-to-the-national price of hay.
5. Pasture Acres per farm.
6. Dairy Cows Milk cows/farm--Data on the number of cows are found in the 1974 Ag. Census and these are adjusted by the ratio of state-to-the-national average price for cows.
7. Research Total expenditures on research for the dairy category in the CRIS data.

III. Poultry

Variable

1. Output Value of poultry and poultry products sold per farm. Same type of adjustments as for dairy only items are broilers, turkeys, and eggs
2. Land See "Dairy" discussion.
3. Labor See discussion under "Cash Grains" farms.
4. Feed See discussion under "Dairy" farms.
5. Poultry Purchased Value per farm adjusted by ratio of national to state average price.
6. Research Total expenditures on Poultry research.

IV. Livestock Other Than Dairy, Poultry and Specialty

Variable

1. Output Data on number of cattle and calves sold, hogs and pigs sold, and number of sheep and lambs sold can be found in the Ag. Census. Data on value of production per animal is derived from the value of production, and number of animals sold data in Meat Animals, USDA publication. Multiplying the value of production per head by the Ag. Census data gives a value of output which takes out the double counting due to sale of feeder cattle, pigs, and sheep within the state.
2. Land See "Dairy" discussion.
3. Labor See discussion under "Cash Grains" farms.
4. Feed See discussion in "Dairy" section.
5. Livestock Number of breeding stock for beef cows, swine, and sheep times their value per head times .15 plus livestock purchased.
6. Research Research expenditures on Cattle, Swine, and Sheep and wool categories from CRIS data.