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RELATION BETWEEN CROP YIELDS AND ESTIMATED RETURNS TO SCALE AND RETURNS TO RESEARCH

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Abstract

Yields of four major crops in eight midwestern states are compared among 10 sales classes. Yields of these crops are nearly twice as high on the largest farms than on the smallest. Higher quality land and management resulting in higher applications of fertilizer and chemicals on large farms appear to be the leading causes of these yield differences. No major differences are observed in the stock of machinery and equipment per acre among the 10 sales classes. For the country as a whole, those states with the largest average size of farms more closely share the characteristics of the larger farms in the 10 sales classes than do states with smaller than average farms. Unless land and management quality are included and accurately measured in production, profit, or cost functions, there will be an unexplained residual positively correlated with farm size giving the appearance of scale economies even when none exist. Average farm size and the unexplained residual also are positively correlated with experiment station research per farm causing an upward bias in the estimated returns to research as well.

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The long term growth of farm size in the United States, whether measured by land area, gross output, or value added per farm is well known. The reason(s) for this growth is (are) less clear. Growth of farm size has been commonly attributed to economies of scale or size. However recent studies have questioned the existence of major and widespread scale economies among farm firms, and have offered an alternative explanation for their growth (Kislev, Kislev and Peterson, 1982, 1991).

In this study a phenomenon that appears not to be widely recognized is investigated--the existence of substantially higher crop yields on large farms than on small farms. Other things equal, crop yields should not depend on the size of the field or farm. Yet higher yields can result in lower average total costs and give the appearance of scale economies. Thus what appears to be scale economies can instead be a totally different phenomenon. Scale economies are generally defined as the more efficient utilization of conventional inputs. The results of this study suggest that the unexplained output that tends to be labelled as scale economies, is the result of higher quality land and management which in turn give rise to higher yields on larger farms, and not the result of a more efficient utilization of conventional inputs such as machinery and equipment.

The Data

Volume 2, part 5 of the 1987 Census of Agriculture, "Government Payments and the Market Value of Agricultural Products Sold" contains data on acres and harvested output of 12 major crops for each state by 10 sales classes of farms ranging from $1,000,000 and over to less than $2500. Sales figures by the 10 size classes for all crops and livestock products also are presented along with data on government payments and selected inputs. We begin by focusing on 8 midwestern states--Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, and Wisconsin. These states are relatively similar regarding the agricultural environment, thereby facilitating comparisons among farms. Later in the paper a wider sample of states is considered.

Average yields of four major crops grown in these states--corn, soybeans, wheat, and hay--are presented in Table 1. Yields of the first three are nearly twice as high on the largest farms than on the smallest. For hay the difference is more than two times. The data do not allow a comparison of livestock productivity across sales classes.

Possible Explanations

1. Data accuracy. Census data comes from information provided by farmers. The yield differences shown in Table 1 could be due to systematic over-estimates of production by larger farmers and under-estimates by small ones. However there is no evidence to suggest that such a large systematic bias exists in the data nor is there a good reason to believe that such a bias should exist. Therefore this explanation is set aside.

2. Crop failure. One might expect farms which experienced a crop failure to exhibit lower yields and have less to sell thereby placing them in a smaller sales class. However as shown in Table 2, the smaller sales classes coincide with smaller land areas per farm. If crop failure was the primary reason for lower yields on small farms, yields should be correlated with percent of crops failed but not necessarily with land area. Thus the evidence does not support the crop failure hypothesis as a major explanation for yield differences.

3. Land quality. The Census does not provide direct measures of land quality such as soil type or rainfall by sales classes. However some indirect evidence is presented including percent cropland of total land, percent

Table 1

Yields by Size Class - 8 Midwestern States

Sales($1000)	Corn (bu./acre)	Soybeans (bu./acre)	Wheat (bu.Acre)	Hay (tons/acre)
≥ 1,000	134	41.4	51.3	3.25
≥ 500	129	41.0	49.7	3.06
250-499	125	40.1	48.7	2.99
100-249	122	38.0	47.1	2.84
50-99	111	36.0	45.3	2.61
25-49	105	34.8	42.8	2.19
10-24	98	32.6	40.1	2.03
5-9	90	29.9	38.2	1.80
2.5-4	82	27.0	30.2	1.64
< 2.5	74	23.5	26.0	1.37

Table 2

Land Characteristics by Sales Class*

Sales ($1000)	Land per farm (acres)	Percent cropland	Percent cropland pastured	Percent woodland	Percent farmstead and wasteland	Percent failed crops
≥ 1000	1500	82	3.3	6.0	5.0	.21
≥ 500	1314	86	3.3	4.8	4.4	.37
250-499	930	88	3.9	4.9	3.6	.23
100-249	558	86	5.7	6.7	3.8	.36
50-99	344	82	8.4	9.2	4.3	.46
25-49	300	78	11.1	12.1	5.1	.70
10-24	149	71	15.5	16.1	6.5	1.08
5-9	101	62	21.6	21.7	8.4	1.49
2.5-4	75	55	27.2	25.4	10.6	2.36
< 2.5	55	47	33.3	28.3	13.7	5.03

*Figures do not add up to 100 because pastureland and rangeland other than cropland and woodland pastured are not included.

pasture, percent woodland, and percent of total land in farmstead and other waste land. These measures are presented in Table 2. Some significant differences show up in these figures. First, the large farms have a substantially larger percent of their land as cropland than their smaller counterparts. By the same token the percent of cropland pastured, percent woodland, and percent farmstead and wasteland all are much larger on the smaller farms. These figures strongly suggest that large farms have higher quality land than small farms. It appears that large farms, at least in these states, have a preponderance of heavier prairie soils whereas lighter forest soils and hilly terrain are more common on small farms.

Topography more conducive to the use of larger machinery is one possible explanation for the prevalence of better soil on large farms. Prairie soils tend to be relatively flat or gently rolling making for large, rectangular or square fields more conducive to the use of large machinery. Conversely in the forest soils and hilly areas, fields tend to be smaller and irregular in shape--less conducive to the use of large machinery. Hence farms tend to be smaller. Because of the lighter and more erodible soils on small farms, one would expect crop yields to be lower. The existence of lighter, less fertile soils on small farms also makes these farms more susceptible to drought and crop failure which could explain the larger percent of failed crops on these farms.

Differences in management ability among farmers also could account for the positive correlation between farm size and soil quality. If management ability and soil quality are complements, the VMP of high quality land should be higher for the better farmers enabling them to bid this land away from their less skillful counterparts. Since better managers also can be expected to operate larger farms, farm size and soil quality will be positively correlated. This is not to say that superior managers are found only on good land. Most farmers operate farms previously owned by parents or family members. Therefore in areas where land is of lower quality, there still should be some superior managers. However the proportion of good managers is likely to be smaller on poor land because higher earnings opportunities in nonfarm employment can be expected to pull a greater percent of superior managers out of agriculture in these areas.

4. Fertilizer and Chemicals. As shown in Table 3 the dollars of fertilizer and chemicals applied per acre of land in crops are over three times larger on the largest farms than on the farms in the smallest sales class. One would expect, of course, that yields would be higher where fertilizer and chemical applications are higher. The question then becomes "why do operators of large farms apply larger quantities per acre of fertilizer and chemicals?" Large farms may receive quantity discounts and purchase their fertilizer and chemicals in bulk thereby paying slightly lower prices for these inputs. But the price difference between large and small farms is not likely to be large enough to account for this large difference in their use.

The higher level of application of fertilizer and chemicals among the larger farms in a price environment that does not vary greatly among size classes suggests that the VMP curves of these inputs for large farms lie to the right of those on small farms. Again, the question is why? A possible answer is a complementary relationship between fertilizer and chemicals and land and management quality. Two inputs are complements when the MPP (or VMP) curve of one increases, or shifts to the right, when more of the other is

Table 3

Input Applications per Acre (Dollars)

Sales ($1000)	Fertilizer[a]	Chemicals[a]	Machinery[b]
≥ 1000	$39.64	$30.18	$279
≥ 500	35.08	23.54	201
250-499	30.78	17.58	183
100-249	28.13	15.38	194
50-99	24.52	13.72	192
25-49	22.19	13.30	190
10-24	19.82	12.24	192
5-9	17.14	10.13	207
2.5-4	15.58	9.14	213
< 2.5	12.91	7.93	177

[a]Per acre of land in crops.

[b]Per acre of all land.

added. On farms where land and management quality are high the MPP or VMP curves of fertilizer and chemicals must lie to the right of those when they are low, else larger quantities would not be used, given relative prices.

The stock of machinery and equipment per acre, shown in Column 3 of Table 3, does not exhibit a trend across size classes. Machines do not appear to enhance yields. Of greater interest is the fact that small farms do not exhibit larger stocks of machines per acre. These figures do not support the hypothesis that economies of scale exist because machines are lumpy and that their annual cost can be spread out over a larger acreage as farm size increases. Machines come in a variety of sizes; small farms utilize small machines. And because of the smaller number of hours of annual use, small farmers are more likely to purchase used rather than new machinery, thereby holding down machinery costs. These figures probably understate the true machinery investment on larger farms because machines tend to be depreciated more rapidly than their service flow declines. The difference is likely to be greatest for relatively new machinery. Hence the machinery input is likely to be understated on large farms. Annual interest plus depreciation of machinery would be a better but still imperfect measure of this input. However this information is not available by sales classes.

5. Management Quality. There can be little doubt that management ability of operators on profitable farms selling $500 thousand to over one million dollars per year of products must be higher than on farms selling $10,000 or less per year. Indeed large farms require more management skill just to maintain the same level of productivity, as small farms. Given land quality, higher crop yields on large farms requires that management quality on

large farms more than offsets the increased management requirement on these farms.

An independent and accurate measure of management ability does not exist. Years of schooling frequently has been used as a proxy, albeit an imperfect one, for this input. Unfortunately the census does not report years of schooling by sales classes. Information on the average age and age distribution of farm operators by sales class is provided, however. Although age is not a satisfactory measure of management ability either, one might hypothesize that operators in their prime working years but having acquired some management experience, say in the 25 to 64 age range, would be better managers than young people "learning the ropes," or older semi-retired operators. Of course, considerable variation within age groups is bound to exist, particularly among small and mid-sized farms where further growth is a viable option.

As shown in Table 4, there is not a large difference in average age, or the age distribution among the sales classes. The small percent of operators below the age of 25 in the very largest farms is not surprising; it takes some time to accumulate enough capital to generate $500,000 to over $1,000,000 of sales annually. There is some indication of the semi-retirement phenomenon as the percent of operators age 65 and older increases as sales decrease. But in general the age distribution does not exhibit large differences over the sales classes.

Part-time, off farm work is not necessarily an indication of management ability. Good managers may hold off-farm jobs because of their high opportunity cost. By the same token, less able managers may work off the farm because of their low earnings in agriculture. Also it is common for young

Table 4

Operator Age Characteristics

Sales ($1000)	Percent of farm in each age group by sales class					Average Age
	< 25	25-44	45-54	55-64	≥ 65	
≥ 1000	.4	31.4	27.7	27.3	13.2	50.9
≥ 500	.6	33.9	28.2	26.9	10.4	49.9
250-499	.8	40.5	27.7	24.1	6.9	47.8
100-249	1.6	41.6	24.7	24.4	7.7	47.2
50-99	2.7	38.1	21.6	26.0	11.6	48.2
25-49	3.1	33.6	19.5	24.8	19.0	50.4
10-24	2.9	30.2	19.2	25.5	25.2	52.3
5-9	2.4	29.6	19.8	21.4	26.8	53.0
2.5-4	2.3	30.5	21.4	21.3	24.5	52.5
< 2.5	1.9	35.3	23.6	20.2	19.0	51.0

people just getting started in farming to supplement their earnings by off-farm employment, whether they are good managers or not. On the other hand, given the skill of the manager, responsibilities of off-farm work can have an adverse effect on yields by affecting the timing of field operations. For example, the crops may not be planted, cultivated, sprayed, or harvested at the optimum times if off-farm job responsibilities take precedence over farm work.

Percentage figures of farm operators engaged in off-farm work by sales class are presented in Table 5. As expected, the percent of farm operators holding off-farm jobs increases as sales decrease. These figures probably understate the extent of off-farm work especially for the smaller sales classes because spouse and/or other family members are excluded. No doubt farm income represents a small proportion of total family income for the small farm categories. However, no information is provided on total off-farm labor or investment earnings by sales classes.

Yield Functions

Further insights on sources of yield differences across sales classes might be gained by estimating a "yield function." Essentially this is a partial production function with value of crop production per acre as the dependent variable. The 12 field crops are aggregated by assigning values using a common national average price for each crop. Because vegetables, fruits and nuts are not included in the production figures of the 12 crops, total value of crop production per acre is obtained by summing the value of production of the 12 field crops plus the sales of vegetables, fruits and nuts. Total crop <u>sales</u> figures are not appropriate because part of the field crops are marketed through livestock, especially hay and feed grains. However

Table 5

Percentage of Farm Operators Holding Off-Farm Employment, by Number of Days

Sales ($1000)	1-99	100-199	200 days or more	Total
≥ 1000	8.0	2.8	8.1	18.9
≥ 500	8.9	2.5	6.2	17.6
250-499	11.9	3.0	4.7	19.6
100-249	14.3	4.6	7.2	26.1
50-99	14.0	7.6	15.4	37.0
25-49	11.2	9.4	27.7	48.3
10-14	8.7	9.6	39.1	57.4
5-9	7.2	9.4	46.8	63.4
2.5-4	6.4	8.7	52.8	67.9
< 2.5	5.8	8.4	59.4	73.6

virtually all production of vegetables, fruits, and nuts are sold as cash crops. Thus value of production of the 12 field crops plus sales of these horticultural crops should provide a reasonably accurate measure of total crop production by sales class.

Regarding the explanatory variables, expenditures on fertilizer and chemicals are aggregated to form one variable because of their high intercorrelation, r = .96. The high intercorrelation among all the conventional inputs including land, labor, machinery, fertilizer, chemicals, feed, seed, and miscellaneous inputs precludes the estimation of a full per farm production function. Virtually all the simple r's are in the range of .90 to .95. This is not unexpected since farms face common input prices and the 8 states have similar agricultural environments.

Land quality is measured by the percent of cropland in total land. Admittedly this is an imperfect measure, but it is the only one available. Percent of farm operators in the 25 to 64 age bracket, and percent of operators working 200 days or more off the farm are proxies for management quality. For the most part, farmers working 200 days or more off the farm have full time jobs which are more likely to interfere with proper timing of field operations than part-time jobs. Again these measures of the management input are grossly inadequate but no other measures for sales classes are available.

To take account of differences in crop mixes across sales classes and states, percent of corn and percent of vegetables, fruits, and nuts of total crop production are added as explanatory variables. These crops tend to be higher value per acre crops than soybeans, grains, and hay and typically receive heavier doses of fertilizer and chemicals.

Table 6

Yield Functions
(Dep. var.; value of crop production per acre)

	(1)	(2)	(3)
Fertilizers and Chemicals	.287 (3.65)	.279 (3.54)	.320 (3.81)
Percent cropland	.185 (.669)	.241 (.875)	.747 (3.03)
Percent 25-64 age	-.829 (-2.40)		.001 (.083)
Percent ≥ 65 age		.876 (2.40)	
Percent ≥ 200 days O.F.W.	-.718 (-3.60)	-.690 (-3.60)	
Percent corn	.445 (3.45)	.444 (2.05)	.291 (1.27)
Percent vegetables, fruits and nuts	.605 (3.45)	.598 (3.42)	.573 (3.04)
R^2	.854	.854	.828

* Figures in parentheses are t-ratios. A constant term is included but not reported.

The yield function is estimated by a standard Cobb-Douglas (log-log) form. Each of the 10 sales classes is an observation in the 8 states, making a total of 80 observations. The results are presented in Table 6.

Two surprises show up in equation (1): the insignificant but positive coefficient on percent cropland, a proxy for land quality, and the negative and significant coefficient on percent of operators in the 25 to 64 age bracket, a proxy for managerial quality. In equation (2) percent of operators age 65 and above is inserted as a management proxy with similar results. These unexpected results appear to stem from a relatively high negative correlation between percent cropland and percent of operators working off the farm 200 days or more ($r = -.85$). When the off-farm work variable is dropped, the percent cropland variable becomes highly significant as shown in equation 3. Also, as reported in equation 3 the age variable becomes insignificant when off-farm work is deleted. This holds true when age is specified as 65 and over as well (not shown in Table 3).

From these results one might conclude that yield differences are due largely to difference in fertilizer and chemical use and land quality. Full time off-farm work appears to have an adverse effect on yields, although its high negative correlation with land quality makes it hard to tell which is the most important.

The yield function allows the computation of the VMP_s of fertilizer and chemicals by sales classes. Are large commercial farms closer to the profit maximizing level of fertilizer and chemical use than small farms? To test whether the fertilizer and chemical coefficient differs across the size groups, a slope dummy was inserted for the largest 5 classes in an equation comparable to (1) in Table 6. The slope dummy coefficient (.003) was not

Table 7

Fertilizer and Chemical VMPs by Sales Class

Sales ($1000)	VMP	Sales ($1000)	VMP
≥ $1000	$1.13	$25-49	$1.37
≥ 500	1.19	10-24	1.41
250-499	1.24	5-9	1.47
100-249	1.31	2.5-4	1.39
50-99	1.35	< 2.5	1.35

significantly different from zero. Hence the same fertilizer and chemical coefficient is applied across the 10 sales classes. The coefficient from equation (1) is used (.287). The VMP_s of fertilizer and chemicals for the 10 sales classes are shown in Table 7.

Because output and the fertilizer plus chemicals input are both measured in value terms, the VMP is interpreted as dollars of output per dollar of input. Hence profits are maximized when the VMP equals one dollar. As shown in Table 7 the VMPs in all sales classes exceed one dollar but not by much. Hence it appears that farmers in all 10 sales classes are using fertilizer and chemicals at about the levels that maximize profits. The small farms exhibit slightly higher VMPs but are not far out of equilibrium. These results suggest that management skill has a much greater impact on the position of the VMP curves for purchased inputs than on the ability to be at a profit maximizing equilibrium point, assuming that large farms have more able managers than small farms. Of course, part of the reason for the larger application of fertilizer and chemicals can be higher quality land as well as higher quality management, although as mentioned, land quality can in part be a function of management quality.

The fact that large farms utilize two to three times more fertilizer and chemicals per acre than small farms but exhibit about the same VMPs suggests that the VMP curves of fertilizer and chemicals for large farms lie to the right of those for smaller farms. In other words it appears that higher quality land and higher quality management are complements to fertilizer and chemicals. This hypothesis is consistent with the observation that large farms utilize more fertilizer and chemicals per acre of harvested cropland than small farms, and can explain why.

Implications

A. Returns to Scale

Studies reporting the results of production functions fitted to U.S. farm data encompassing the post WWII period consistently report sums of coefficients in the neighborhood of 1.3, implying significant economies of scale (Kislev and Peterson, 1991). However the validity of these results can be questioned on both theoretical and empirical grounds. For example, if the sum of coefficients is really 1.3, then output is overexhausted to the extent that land, the residual claimant, receives a negative return. Clearly this result is inconsistent with a positive land price. Another inconsistency is the finding of a relatively constant 1.3 sum of coefficients over periods when farm size grew rapidly (the 1950s and 1960s), grew slowly (the late 1980's), or did not grow at all (mid 1970 to mid 1980). If the sum of coefficients is an accurate indicator of scale economies, one would expect it to be positively correlated with changes in the growth of farm size.

The evidence presented in the preceding section provides an explanation for the apparent inconsistency between the estimated sum of coefficients and the observed growth of farm size. If the VMP curves of fertilizer and chemicals on large farms lie to the right of those on smaller farms because of their complementary relation with higher quality land and management there will be a residual or unexplained output on large farms if land and management quality are not accurately measured. Since this residual is positively correlated with farm size, it will show up as economies of scale (unexplained output) in production functions. In other words, the sum of coefficients can be an indictor of unexplained output that is positively correlated with farm size rather than of economies of scale.

Figure 1 illustrates the source of the unexplained output. VMP_s and VMP_L are the VMP curves of fertilizer (and chemicals) on small and large farms respectively. The shaded area between the two curves represents the unexplained output that has been mistakenly called economies of scale.

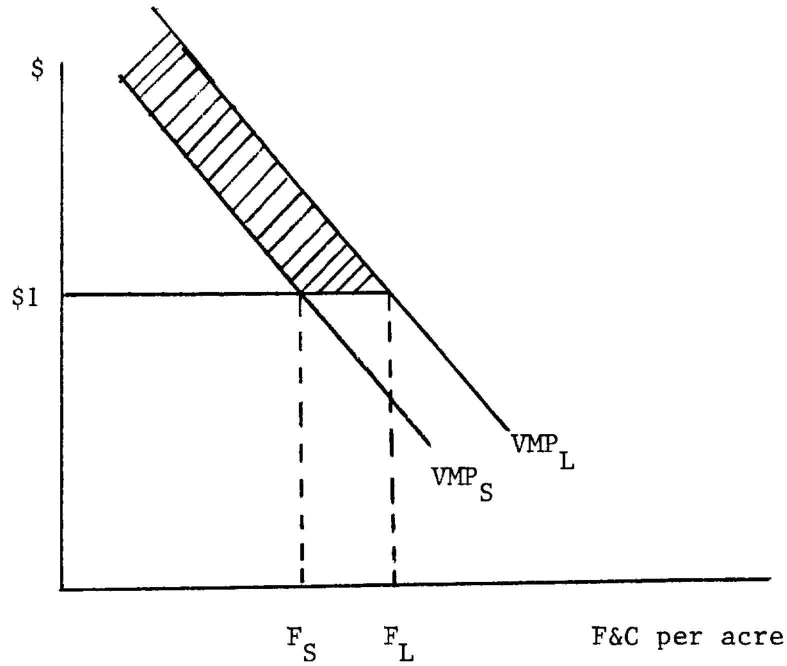
The same phenomenon likely occurs with livestock and poultry. Higher quality animals, birds, and management (unmeasured) should be complementary with feed, causing the VMP curves of feed on large farms to lie to the right of those on small farms. This results in additional unexplained output and gives the appearance of scale economies as well.

Much of the evidence on economies of scale has come from production functions fitted to aggregate data. That is, the average farm in each state is an individual observation. In order for the above argument to apply, states with above average size of farms must exhibit characteristics similar to the large sales classes previously discussed. Similarly states with smaller than average size of farms should be more like farms in the small sales classes. In Table 8, the 10 states in the U.S. with the largest sales per farm (in 1987) are contrasted to the 10 with the smallest annual sales. The difference between the two groups is substantial with the large farm group exhibiting over 3.5 times the average sales per farm of the small farm group.

In the 10 states with the largest farms 88 percent of the sales comes from farms having $100,000 of sales or more. In the 10 states with the smallest farms this figure is 66 percent. Therefore in states with the largest farms a greater proportion of output comes from farms in the large sales classes. And the agriculture in these states more closely resembles the large sales class groups discussed previously.

Figure 1

The Unexplained Residual



As shown in Table 8, per acre expenditures on fertilizer and chemicals are about twice as large in the large farm states as in the states with the smallest farms. Also value of crop production per acre is more than twice as large in the large farm group. Part of this difference is due to the large value of crop production per acre in California, Florida, and Washington--states with substantial fruit and vegetable production. Unless the special climate and soil characteristics of states like these are measured accurately, they will appear more productive than others. Also part-time work participation by operators 200 days or more per year is greater in the small farm states.

Since the prices of fertilizer and chemicals are relatively uniform across the country, the greater use of these inputs among farmers in the states with large farms suggests that their VMP curves in these states lie to the right of those in the smaller farm states. Higher quality land, including climate, and management is a likely explanation. If land quality and management ability are not accurately measured, there will be an unexplained residual (the shaded area of Figure 1) positively correlated with average farm size. This will give the appearance of scale economies in aggregate agricultural production functions, even where none exist.

B. Returns to Research

Much of what we think we know about the estimated returns to research comes from aggregate production function studies fitted to cross section data as described above (Griliches, Peterson, Evenson, Bredahl and Peterson; Davis, Huffman and Evenson; Pardey and Craig). By and large the results of these

Table 8

Selected Characteristics of the 10 States with the Largest Farms and the 10 with the Smallest

Characteristics	10 Largest[a]	10 Smallest[b]
Sales/farm ($1000)	124.9	34.0
Percent ≥ $100,000 sales	88.0	66.1
Fertilizers and chemicals/ Acre ($)	77.11	38.59
Crop production/acre ($)	450	192
Percent ≥ 200 days O.F.W.	33.8	41.1
TRE/1000 farms (#)	13.1	6.9

[a]10 largest in descending order: AZ, CA, DE, FL, CO, NE, CT, KS, ID, WA.

[b]10 smallest in descending order: UT, OH, SC, NH, OK, VA, MO, KY, TN, WV.

studies support the hypothesis that the rate of return to investment in agricultural research is high--in the range of 30 to 60 percent.

There is a danger, however, that the same factors causing an upward bias in estimated returns to scale also are biasing upward the estimated returns to research. As shown by the bottom line of Table 8, the average number of teaching, research and extension (TRE) personnel in the crop and livestock disciplines in each state's agricultural experiment station per 1000 farms is nearly twice as high in the 10 states with the largest farms than in the 10 states with the smallest farms. Hence the research variable will be positively correlated with farm size, and positively correlated with the unexplained residual illustrated in Figure 1. Since higher quality land and management on large farms compared to small farms cannot be attributed to state differences in public investment in agricultural research per farm, the research coefficients in these production function studies will be biased upward which in turn causes an upward bias in the estimated returns to research.

Concluding remarks

It is evident that large farms are not just larger versions of small farms. Higher crop yields on large farms appear to stem from higher levels of land and management quality on these farms. The average farm in states with relatively large farms more closely exhibits the characteristics of farms in the large sales classes. If land quality and management ability are not accurately measured, production, profit or cost functions will exhibit an unexplained residual positively correlated with farm size, giving the appearance of scale economies even where none exist. The positive correlation of experiment station research with this unexplained residual also can result in an upward bias to the estimated returns to experiment station research. Land and management quality are extremely difficult, if not impossible to accurately measure. Therefore the results of econometric studies which attempt to measure returns to scale or returns to research should be viewed with some degree of skepticism.

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