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Impacts of Precision Farming on the Structure of Agriculture (and Related Thoughts)

by

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Introduction

Precision farming is just one of many new technologies in agriculture currently being developed by researchers in both the public and private sectors. Researchers work on these technologies in an effort to increase the productivity of agricultural enterprises and reduce per-unit costs of production. While concern is focused on the possible consequences for increasing profitability of production of a particular enterprise once the technology is in place, there is often little effort devoted to the magnitude of the initial expenditures (capital outlay) required to implement the new technology.

In this paper I first discuss the role of external capital constraints in limiting the ability of farmers to implement new technologies. Via a theoretical model, I illustrate the role of farm size in determining if a particular cost-reducing technology is implemented. I show that the cost savings associated with a new technology capable of reducing per-unit costs of production may not necessarily be accessible to farmers that face significant external capital constraints that limit farm expansion. Finally, I explain why cost-reducing technologies that have high up-front adoption costs act as a driving force for farm size expansion and the consequent reduction in the number of farms—an explanation for the structural changes that have dominated American agriculture for 75 years or more.

The idea that advances in agricultural technologies ultimately lead to a reshaped structure of agriculture with fewer but larger operators is not new. In 1958, Cochrane advanced his so-called "treadmill theory" (see also explanations of the treadmill theory found in Tweeten) which lays out the basic idea that all new agricultural technologies, even the cost-reducing technologies, ultimately are output-enhancing. The increase in output brought about by these technological advances once they are widely adopted ultimately drives down the market prices faced by both adopters and non-adopters. Farmers who fail to adopt the new technologies early ultimately are unable to compete once market prices are driven downward. This puts farmers on a "treadmill." Farmers who wish to remain profitably in business must be cost-competitive, and thus must find a way to adopt each new cost-reducing or output-enhancing technology as soon after it became

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available as possible. Farmers who "drop of the treadmill" sell their farms and see the acreage consolidated in ever larger farming units.

In the aggregate, this drive toward expansion alters the structure of agriculture with respect to the number and average size of farms and the percentage of output accounted for by each size category. Inevitably, with an inelastic demand for US agricultural commodities, as a result of the output-increasing effects of the new technology, revenue (farm income) decreases as the price declines always more than offset any gains in revenue arising from the output-enhancing effects of the new technology (See the discussion in Debertin, 1997)[1].

The Role of Capital Constraints

Farmers face external capital constraints which limit their abilities to expand the scale of their operations and their abilities to adopt the latest in new technologies–technologies that have the potential to significantly reduce per-unit production costs once implemented. These capital constraints are generally more limiting for small farmers than large, since small farmers generally have less access to credit markets. As a result, small farms are less likely to adopt cost-reducing technologies, particularly those that require a significant up-front outlay of money in order to put in place.

The lack of willingness of some farmers to implement the latest in new technologies is sometimes blamed on the farmers' lack of understanding of the technology and how it might reduce per-unit production costs, and technology adoption is thus viewed as a simple matter of "educating" farmers as to its benefits. I believe that far more important, however, is the fact that the initial capital outlay in the adoption of any new technology poses a significant barrier to entry for farmers who lack ready access to capital.

Basic economic theory is used to illustrate the differences in the cost functions faced by the farmer who is severely restricted in the availability of capital for precision-farming technology adoption versus the farmer who has ready access to capital, and to show why farmers continually seek to

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[1] This unending pressure to be cost competitive by adopting each new generation of technologies ultimately drove farmers from the land. Rural communities whose businesses and employment depended on farmers lost population as farmers quit farming. These forces in combination have been responsible for the massive out-movement of people from production agriculture and in large measure are also responsible for the out-migration of the non-farm population in rural areas heavily dependent on agriculture (Goetz and Debertin; Hyde; Krehling, Smith and Luloff). These ideas are further outlined and developed in Johnson and Quance and in Frink and Horsefall. Those writing on economic impacts of agricultural industrialzation on rural areas are dealing with very similar issues and concerns (see Benjamin; Drabenstott; Heffernan; and in Ikerd.) Discussions of the role of agricultural research can be found in Antle; Beattie; Debertin (1992 and 1995); Paarlberg, and in Schuh.

expand the scale of their operations in an effort to further spread high up-front technology adoption costs over a larger quantity of output--reducing average fixed costs per unit of the commodity or product being produced.

A Theoretical Model

Consider a farmer operating under an old, (in this case, non-precision farming) technology who faces a cost function of the form

$$(1) \qquad TC_o = F_o + b_o y^2$$

The new, "challenger" (in this case, precision farming) technology is represented by a similar function

$$(2) \qquad TC_n = F_n + b_n y^2$$

The old technology has lower fixed, or "startup" costs than the new, but the incremental costs that vary with output are higher for the old technology than for the new. This is the cost savings associated with the adoption of the new (precision farming) technology.

Hence,

$F_n > F_o$, and $b_o > b_n$.

As the firm expands, the fixed or startup costs are spread over an ever larger quantity of output (y).

Average Costs are the sum of *Average Fixed Costs* ($AFC = F/y$) plus *Average Variable Costs*. ($AVC = by^2/y = by$)

Thus, *Average (Total) Costs* for each technology are the sum of average fixed and variable costs and are defined as $AC = F/y + by$.

Therefore, the *Average Cost* (startup plus incremental or variable costs) of the *old* (non-precision farming) technology that has lower up-front (fixed) costs but higher incremental costs is

$$(3) \qquad AC_o = \frac{F_o}{y} + b_o y$$

The *Average Cost* of the *new* (precision farming) technology that has higher up-front (fixed) costs but lower incremental costs is

$$(4) \qquad AC_n = \frac{F_n}{y} + b_n y$$

The critical question, of course, is whether AC_o is smaller or larger than AC_n for the individual farmer who is a potential adopter of a precision farming technology. In other words, will the adoption of such a technology lower production costs on a per-unit basis or not given the combination of "fixed" and "variable" costs the new technology represents.

Obviously, to the extent that the new, precision farming technology requires some significant up-front cost outlay [*Example*: expensive harvesting equipment such as a top-of-the- line combine with a global positioning device but reduces the incremental (variable) costs of production once the technology is in place] the answer to this question depends critically on the size or scale of the farming operation. Perhaps the simplest and least troublesome way of measuring the size of an individual operation is to look at the level of production of the commodity in which the precision farming technology would be adopted. A simple example would be a corn producer who is seeking to lower incremental production costs by employing a precision-farming technology in corn production. Thus, output (y) would be measured by the amount of corn produced in an average, year. (This is probably a better measure of size than an input-related measure such as the number of planted or harvested acres.)

An interesting question then, is at what size (corn output level) does the precision farming technology become economically attractive. Obviously the break-even output level (y) for the adoption of the technology is at the point where $AC_o = AC_n$. At below the output level defined by this point, the farmer will not adopt the precision farming technology, since it is not cost-effective to do so, but at above this output level, the precision farming technology will be adopted. The break-even output level for the precision farming technology is thus at

$$(5) \qquad \frac{F_n}{y} + b_n y = \frac{F_o}{y} + b_o y$$

where all variables are as previously defined.

Solving for the output level where precision farming will be adopted can be done in the following steps. First, multiply equation 5 by y to get

$$(6) \qquad y\frac{F_n}{y} + b_n y^2 = \frac{F_o}{y} + b_o y^2$$

Thus,

$$F_n + b_n y^2 = F_o + b_o y^2$$

and

$$F_n - F_o = (b_o - b_n)y^2 .$$

Hence,

$$y^2 = \frac{F_n - F_o}{b_o - b_n}.$$

The output level that represents the break-even level for the adoption of the new (precision farming) technology where $AC_n = AC_o$ is

(7) $$y = \sqrt{\frac{F_n - F_o}{b_o - b_n}}$$

Since the characteristics of the precision farming (n) technology are $F_n > F_o$ but $b_n < b_o$, thus $\sqrt{\frac{F_n - F_o}{b_o - b_n}}$ is non-negative and exists. The new, precision farming technology will be the cost-efficient technology at output levels greater than $y = \sqrt{\frac{F_n - F_o}{b_o - b_n}}$.

A Numerical Example

Now assume some specific numbers to illustrate these concepts. Suppose fixed costs associated with the implementation of the old (non-precision farming) technology are \$5,000 for but for the new, precision-farming technology, these fixed costs are twice as high, or \$10,000. The size of the operation is measured by the amount of grain produced. Figure 1 illustrates Average Fixed Costs as Total Fixed Costs divided by output (the size of the operation).Output could be measured by the quantity of grain (such as corn) produced. Average Fixed Costs remain higher under the precision farming technology than the non-precision farming technology for any specific size level. In this example

$AFC_o = \$5,000/y$ (non-precision farming)

$AFC_o = \$10,000/y$ (precision farming)

Total Variable Costs increase with the size of the operation, but here is where the precision farming technology has an advantage. Precision farming reduces the per-unit variable costs of production. In this example

$$AVC_o = 0.50y^2/y = 0.50y \quad \text{(non-precision farming)}$$

$$AVC_o = 0.15y^2/y = 0.15y \qquad \text{(precision farming)}$$

The two Average Variable Cost functions are illustrated in Figure 2 by two lines with different but constant slopes. The Average Variable Cost function for the old, non-precision farming technology has a steeper slope than the function for the new, precision farming technology.

Average (Total) Costs is the sum of Average Variable Costs plus Average Fixed Costs. So Average Costs under the old (*o*) and new (*n*) technologies are given by

$$AC_o = AFC_o + AVC_o$$

$$AC_o = \$5{,}000/y + 0.50y$$

$$AC_n = AFC_n + AVC_n$$

$$AC_o = \$10{,}000/y + 0.15y$$

These Average Cost Functions are illustrated in Figure 3. Average (production) Costs (fixed or startup plus) variable are lower under the old, non-precision farming technology at output level obtained from equation 7. In this example,

$$y = \sqrt{\frac{10{,}000 - 5000}{0.50 - 0.15}} = \sqrt{\frac{5000}{0.35}} = \sqrt{14285.714} = 119.523 \tag{8}$$

These calculations confirm the crossover point between the Average Cost functions under the old, non-precision farming technology and the new, precision farming technology. The size of the operation must exceed 119.523 units of output for the precision farming technology as illustrated in Figure 3. If, in this example, corn production was the measure of the size of the operation and was measured in thousands of bushels, then a farm would need to be of sufficient size to produce 119,523 bushels of corn for the adoption of the precision farming technology to make sense. The precision farming technology might have impacts on both the amount of corn produced per acre as well as on a reduction in variable production costs, so estimating the exact size of this farm in acres would be more difficult, but, to illustrate, with an average estimated corn yield of 120 bushels per acre, the breakeven size for precision farming adoption would be at approximately 1,000 acres of corn.

The numbers in this example are hypothetical, but illustrate the kinds of calculations that could be done from detailed farm records cost data. It is important to recognize that this analysis applies to the farm firm operating under capital constraints that limit the firm's ability to increase output to the point where *Marginal Cost* equals *Marginal Revenue.* Hence, producers are finding economic solutions under conditions of constrained optimization, not solutions that maximize profits globally.

Impacts of New Technologies on the Structure of Agriculture

Agricultural research has traditionally focused on "successes" in improving the productivity of agricultural enterprises through increasing the output of crops and livestock, and stressed the role of new technologies in achieving these output increases. We as researchers frequently assume that if we are successful in achieving gains in agricultural output as measured by increases in cash receipts paid to farmers from the sale of crops and livestock, somehow the net incomes of farmers are increased and therefore the lives of farmers will be improved. But the critical question is not the issue of whether a particular new technology can be shown as successful in increasing crop yields. Rather, the question from a financial perspective is whether or not an incremental increase in capital invested in the new (precision farming) technology is economically warranted given the costs of putting the technology in place. The critical economic issue in the adoption of precision farming is determining from a capital budgeting perspective (1) does such an investment make sense given the current size of the farming operation; or (2) if not, might it make sense if the size of the farming operation is expanded. If the latter, there could be impacts on the structure of agriculture as well.

As indicated earlier, no new technology is implemented immediately by all producers. Not surprisingly, given the arguments and theory outlined above, it is generally the farmers whose capital constraints are least limiting who are likely to be the early adopters. As the theory illustrates, this is likely to be the largest producers, who, recognizing the variable cost savings that are possible on a large operation (where the adoption startup costs can be spread over a large number of units of output) are willing to commit the up-front capital to put the technology in place. These large-scale operators quickly become the low-cost producers, in the aggregate, increasing the quantity of output that is produced and driving down market prices for all producers. In the short-run, these large-scale producers are better off because, having spread their start-up costs over a large amount of output, they are able to produce at cost levels that are significantly below the price levels in the marketplace and for a period of time remain quite profitable.

Smaller farms, those with more limited capital and less means to spread the startup costs of implementing the technology, are increasingly affected by the competitive pressures of the marketplace where prices are being driven down by the aggregate impacts of the output from large-scale farmers–those who have already adopted the technology (and who are extracting "rents" from their competitive position because of their size).These smaller farms are under increasing economic pressure brought about by the marketplace to expand the size of their operations so that the new technology can be adopted and they can return to profitability. Access to capital markets may limit this possibility. Gradually over time, the costs of adopting the new technology will likely decline, and the startup costs will pose less and less of a barrier to adoption by smaller operators. As adoption becomes increasingly widespread, even among smaller producers with more limited capital constraints, the price of the agricultural commodity being produced using the new technology further deteriorates. The financial position of many farmers who have been unable to expand and adopt becomes increasingly precarious. Farms that are unable to expand are driven out of business and the land once in these farms is consolidated into ever larger production units that can afford the new technologies. This is the technology-driven change in the structure of agriculture leading to rapid declines in farm numbers and increases in average farm size.

The story does not end there, however. Large farmer operators, having already achieved the cost savings associated with the adoption of the this now familiar technology, find their own profits eroded as adoption becomes widespread and market prices further deteriorate. This, in turn leads to a quest for yet another technology in an effort to repeat the process and return to profitability. For the large-scale producers operating with few capital constraints, the ideal "next" technology would again be one in which the startup costs once again will pose a significant barrier to quick and widespread adoption so that market prices stay well above production costs. Such a large-scale producer can once again take full advantage of its size to spread what smaller firms would consider to be excessive adoption costs over an even larger amount of output. This will enable the large-scale operator to again extract the economic "rents" achieved because of the reductions in per unit production costs brought about by the technology adoption. From the perspective of a large-scale producer, if the barriers to adoption for other, smaller-scale producers are high, and, as a result, widespread adoption is slowed, all the better. This will enable the large-scale producer to extract these economic rents for a longer period of time before moving on to yet another cost-reducing technology. Even the large-scale producer will likely find it necessary to expand further to take full advantage of the next generation of technologies. Census of Agriculture data bear this contention out, in that even producers with more than a million dollars of gross sales are, on average, still growing bigger and bigger.

Concluding Comments

Since its inception, the publicly-supported system of agricultural research and education has been built on a quasi-religious doctrine that I call "agricultural evangelism." Central to agricultural evangelism is the goal of improving the lives of rural people, especially farmers. In this context, evangelism means spreading news of the "truths" developed through agricultural science, and informing (educating) these people of new ideas developed through science. This goal is often pursued by agricultural educators with a nearly religious fervor.

Like religious leaders, agricultural scientists and educators are frequently uncomfortable in situations where their "students" such as farmers, or, more generally, all rural people, reject "truths" from agricultural science that seem to be in their apparent short-run best interest. If agricultural extension is to be successful, educators often believe that they must observe changes in the behaviors on the part of the people (in this case, farmers) they are trying to educate. These changes in behavior are manifested in the adoption of new productivity-enhancing and cost reducing technologies in agricultural production. Agricultural scientists[2] are often also uncomfortable in confronting the unintended aggregate consequences of ideas that appear to be very much in the short-run best interest of the individual farmer.

But this paper has argued that farmers who choose not to adopt precision farming technologies may also be behaving rationally, given the economic conditions and constraints under which they operate. The economic theory of rational choice plays a critical role here, for rational choice suggests that farmers who choose not to adopt new technologies after being informed of the potential productivity gains may still be making wise choices–choices not grounded in ignorance, but logical choices given the capital, size and other constraints that they face. We would like to believe that the primary explanation why farmers fail to adopt new technologies is out of ignorance of their benefits, but this explanation is probably valid only in the minority of cases. Far more important is our failure to recognize the role that capital and size constraints play in technology adoption. This constitutes a critical lapse in the researcher's and educator's understanding of the technology adoption process.

One immediate implication of this analysis is that in evaluating precision farming technologies, an extraordinary emphasis should be placed on analyzing the "up front" capital outlay costs of implementing the technology. an important question related to adoption is that of comparing various technologies falling under the umbrella "precision farming" label, with respect to the initial capital outlay required to implement the specific technology. The goal should be to attempt to find approaches that in a significant way limit the initial capital outlay needed to put the technology in place.

To the extent that new cost-reducing technologies can only be implemented by large-scale farmers, this pushes farm consolidation forward and changes the structure of agriculture as farmers attempt to expand enough to spread costs associated with the high initial capital outlay over a larger quantity of output. There are opportunities as well for innovative financial approaches that would permit small farmers with limited access to capital to obtain the technologies via lease or rental arrangements that would not require large capital outlays.

As an empirical effort, we are in the process of examining the detailed farm records for 80 of the producers who are involved in the Kentucky Farm Business Analysis program. We have access to a detailed data set for each producer who has participated in the program over a 10-year time period from 1988-97. These data are interesting not only from the perspective of considerable detail, but also because they include a diverse array of farmers that widely vary in size and output level, some with very limited capital constraints but others whose capital constraints are far less

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[2]At least, agricultural scientists outside of a small group of agricultural economists who have devoted careers to studying aggregate long-term impacts of technology adoption in agriculture.

limiting. Only two or three of these farmers have currently implemented any precision farming technologies. These farmers will make interesting subjects to study with respect to factors that influence the adoption of precision farming technologies because we have a long historical financial record on each along with detailed information with respect to capital constraints.

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Figure 1. Average Fixed Cost--Without and With Precision Farming

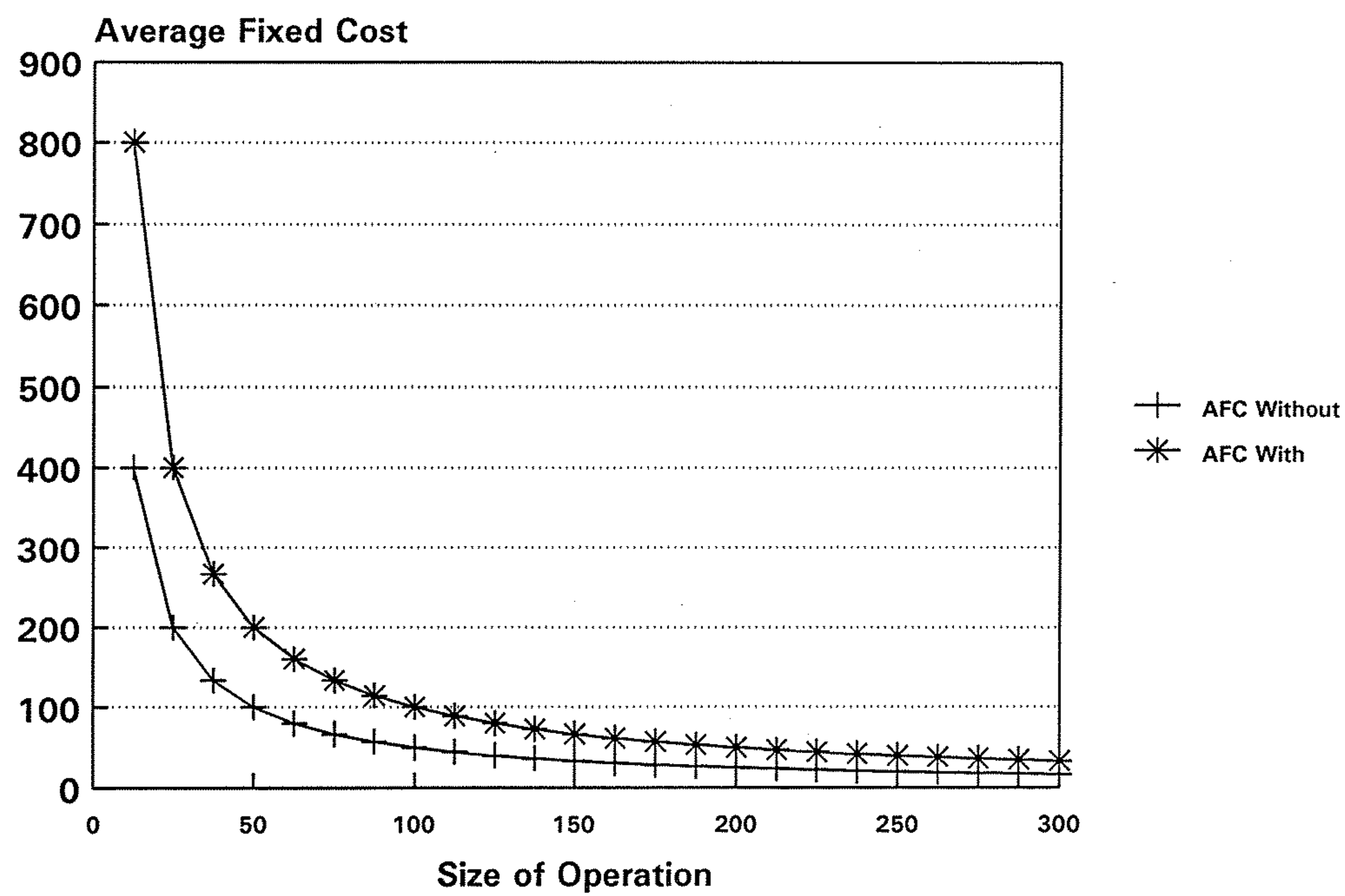
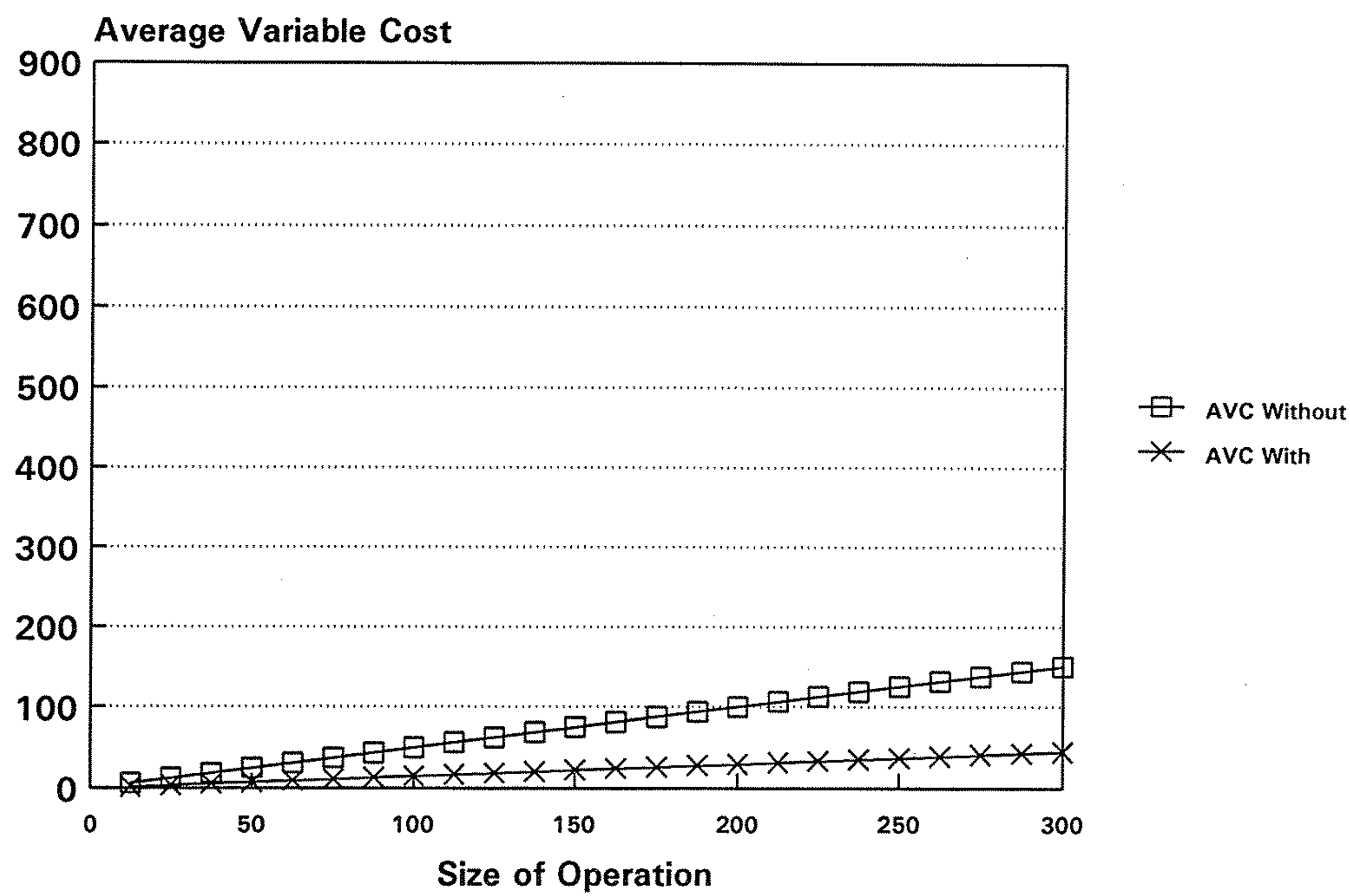
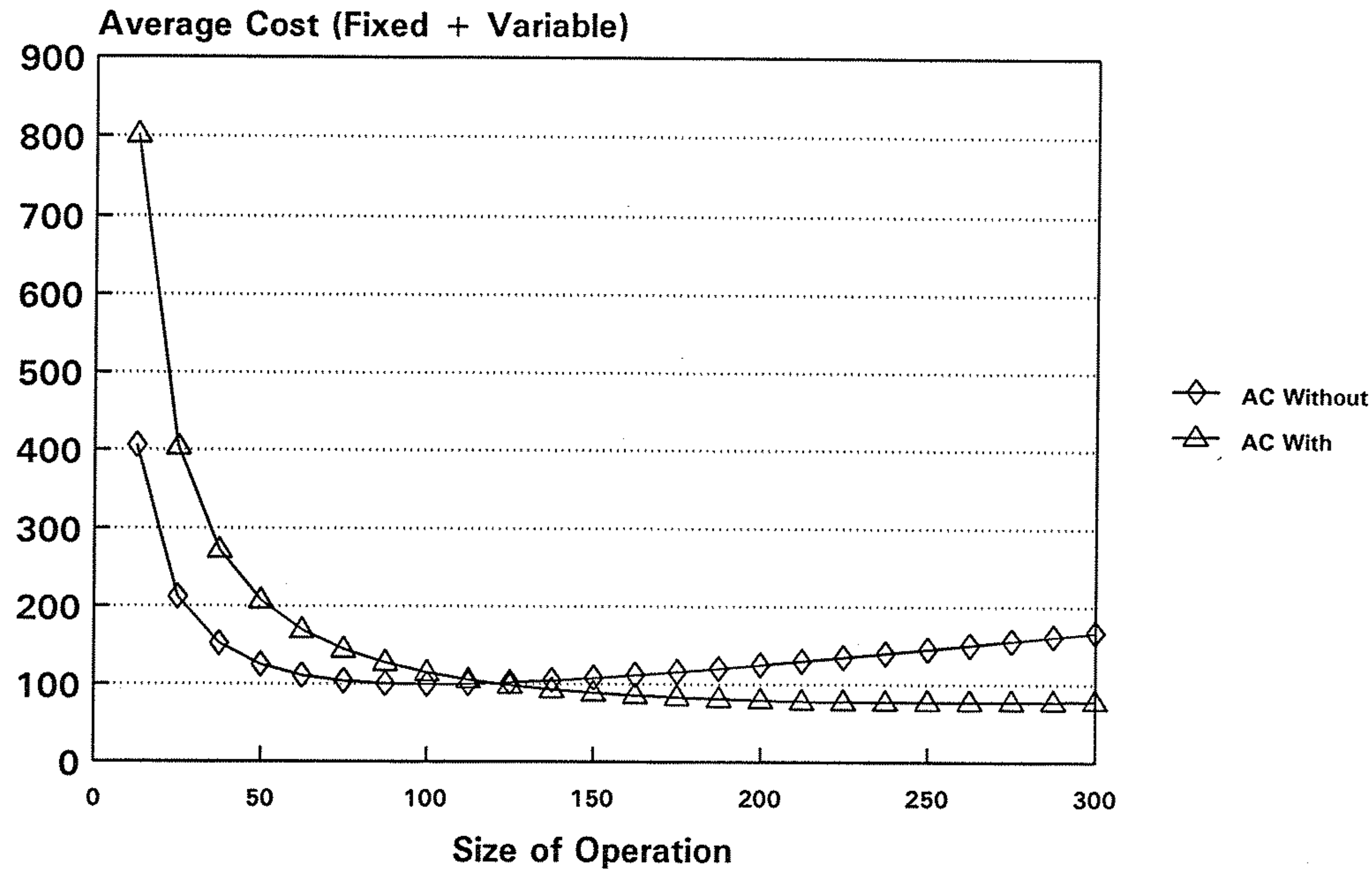


Figure 2. Average Variable Cost, Without and With Precision Farming



AVC= (Total Variable Cost) / Output

Figure 3. Average (Total) Cost, Without and With Precision Farming



Average Cost = Average Fixed Cost
+ Average Variable Cost