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The farm size distribution in American agriculture is the result of historic land settlement patterns as modified by technology, institutional factors, and the economic environment (O.T.A. p.112). The dominant factors shaping farm size structure have been technological change and the competitive economic environment. Government policies have been less important because the United States has not had a well-defined farm size policy (Robinson p.132). This paper discusses the role of technology in shaping the size of farms by examining technology adoption rates. Two empirical studies are presented to test hypotheses concerning the relation between farm size and technology adoption.

## Technology Size Relationships

Economic theory uses the long-run cost curve to explain firm size changes in a competitive industry. Firms tend to move toward the low portion of the cost curve. Large ranges in existing farm sizes for most products attest to a fairly flat long-run cost curve over wide farm size ranges. Technological advances have not only lowered average costs but have extended the size over which costs have remained low. For example, machine technology has reduced costs more for large farms than for smaller ones. The consequences of technological advance has been the continuing movement towards fewer and larger farms.

The relationship between technology and the shape of the long-run cost curve involves three issues. These issues are technical efficiency, pecuniary economies, and the rate of technology adoption. Technical and pecuniary economies of farm size are forces that affect the long-run cost

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curve within a static dimension. But when expanding the analysis to a dynamic dimension, the rate of technology adoption also affects the long-run cost curve.

Technical economies of size are most evident for mechanical innovations. This is, in part, due to the fixed cost component in the manufacture of machinery. Because of these fixed costs, a 200 HP tractor, for example, does not cost twice as much as a 100 HP tractor. More important is the savings in labor associated with large machinery. Assuming one operator per machine, the larger the machine the lower the labor cost per unit of output. The most economic size of machine in the long-run becomes the largest that can be economically built and efficiently used.

Technical economies of size are most accurately measured through the economic-engineering or synthetic firm approach (Madden p.29). Short-run cost curves are generated for firms with increasingly larger machinery complements and more workers. The envelope curve of these short-run cost curves defines the long-run cost curve or planning curve. These studies assume the use of the least-cost technology available for firms of all sizes. Prices paid for inputs and received for products are also often assumed to be constant with farm size.

Pecuniary economies associated with farm size have been found to be important. These economies often begin where technical economies are nearly exhausted (Smith, et al.). Most pecuniary economies result because of savings achieved by input and marketing firms through volume sales, which can be passed on to the farmers. An example would be the lower cost of delivering and billing 1000 gallons of diesel fuel over 100 gallons. Increased bargaining power by operators of larger farms represent a potential to obtain discounts above the cost savings of the marketing firm.

Technical and pecuniary economies are static concepts that can be analyzed through the comparative statics of conventional economic theory. The dynamics of a constant stream of new technologies being developed and adopted must also be considered when looking at economies of farm size in relation to the structure of farming. Economic theory assumes that firms of all sizes use the least-cost technology to produce a given level of output. However, this is not a valid assumption when comparing farms of different sizes in a dynamic world. Technology adoption studies show early adopters to be wealthier and operate larger farms (Feder, Just, and Zilberman).

The process of economic adjustment to farm technological advance is explained by the theory of the treadmill (Cochrane pp. 387-390). The innovative and early adopters of technology reap a gain from lower unit costs. As others also adopt the technology, increased supply of product drives down price, eliminating the profit. Farmers are caught in a treadmill to rush to adopt a new technology to capture the "adoption rents." The laggards on the other hand are forced into a situation of economic loss and eventually are out of business.

Economies of farm size arise from the combined effects of technical, pecuniary, and technology adoption advantages associated with larger farms. Farm size studies using farm accounting data can capture all three of these effects. However, the relative importance of each would not normally be determined. If additional information on prices paid and received and the technology used were also collected, an estimate of the relative importance of each could conceivably be estimated. The synthetic firm approach could take all three effects into account but would depend on accurate estimates of pecuniary advantages and rate of technology adoption differences among farm sizes.

## Technology Adoption and Farm Size

The relationship of farm size to adoption depends on fixed costs of adoption, risk preferences, credit constraints, human capital, and labor considerations (Feder, Just, and Zilberman, p.273). Fixed costs are associated with indivisabilities and directly affect the economics of adoption by farms of different sizes. Farm size also serves as a surrogate for the other factors listed. The influences of these factors therefore varies by area, technology, and over time.

Most mechanical technologies are indivisible and have fixed costs that decline with increased annual use. These technologies have a threshold farm size before they have any economic advantage. Beyond the threshold size the economic incentive to adopt is a function of enterprise size up to machine capacity. The possibility of renting a fixed input can mitigate the indivisability problem smaller farmers confront. The articulated 4-wheel drive tractor is a good example of a technology having a large-farm-size threshold. For example, Rodewald and Folwell in 1977 estimated the economic threshold for adopting a 4-wheel drive tractor to be 2,000 acres in eastern Washington. Renting of 4-wheel drive tractors has not been widely practiced.

Divisible technologies such as pesticides and improved varieties are often described as size neutral. However, higher adoption rates by larger farms can, in part, be explained by learning cost (Feder and Slade, p.316). The fixed cost of learning how to use a complex technology can be justified by the number of units over which it can be used. When learning costs are considered, even divisible inputs have a fixed component that makes the technology no longer size neutral. Only when learning costs are negligible can a technology be truly size neutral.

A new technology may either increase or decrease the variability in yield. Improvement in the level of output, even though the yield has a higher variance, may still result in a lower probability of losses below the original mean or a target income level. However, farmers' technology choices are based on their subjective probabilities of gains and losses and hence on acquired information regarding new technologies. Because information acquisition represents a fixed cost, the economics of information acquisition favor larger farms. The ability to take on risk is more a function of the capital structure of the farming operation than size. Because larger farms are typically more leveraged than small farms, they may be less able to withstand risk. The degree of personal risk aversion, however, is probably lower for the operators of larger farms.

Credit constraints tend to limit the adoption of technology. Credit constraints are especially limiting for indivisible technologies but also have been found to limit use of divisible technologies (Feder, Just, and Zilberman, p.278). Capital in the form of accumulated savings or access to capital markets is typically more available to larger farms.

Education level is usually used to measure human capital. In some cases education may be a proxy for intellectual ability or it could be looked upon as a consumption good associated with wealth. With competitive market forces, larger farms probably attract a higher level of human capital than smaller farms. Especially in the context of rapid technological change, several studies show that farmers with better education are early adopters and apply new inputs more efficiently throughout the adoption process (Feder, Just, and Zilberman).

Labor availability in a family farm context is more abundant and has a lower opportunity cost on smaller farms. Therefore, labor saving technologies are more economic for larger farms aside from the fixed cost consideration. Yield-increasing technologies tend to increase harvesttime labor shortages, which could hinder adoption by larger farms where labor is relatively more scarce (Feder et al., p.277). Although seasonal labor shortages have been found to have a negative effect on high-yield technology adoption in developing countries, labor bottlenecks probably are less important for highly mechanized United States agriculture.

In summary, large farms have direct economic incentives to be early adopters of new technology. Also, several factors associated with large farms argue for the early adoption of new technology. Ruttan found differential adoption rates of divisible technologies to disappear once the adoption process is sufficiently advanced. The economic advantage for the early adopters still makes it possible for them to acquire more wealth and bid resources away from the laggards. The farm size structure is clearly affected not only by technological change but also by the rate of introduction of these changes.

## Technology Classification

Investigations into technological adoption farm size relationships need to carefully identify technology characteristics that affect these relationships. Technologies need to be classified according to the dimensions that influence adoption. The following classification scheme is suggested.

1. Divisibility. Although viewed as a dichotomy between divisible and indivisible, the notion of a minimum size for profitable adoption of indivisible technologies differs depending on other technology characteristics.

2. Complexity. A continuum from very simple to complex. The time and effort involved in learning the new technology should be the criteria for classification.

3. Capital requirements. Most technologies increase total production costs for the firm but are economic because the value of the marginal output is greater than the cost increase. These are usually referred to as output-increasing technologies. However, there are technologies which have a lower cost than that of existing methods and can be economic with constant and even reduced output. This classification has implications for credit constraints and risk considerations. A possible measure would be the change in total production costs for the firm.

4. Labor effects. Labor-saving technologies usually have little or no effect upon output. Output-increasing technologies sometimes also increase labor needs at critical time periods. Because the opportunity cost or availability of labor may be farm size specific, the labor effects need to be considered.

5. Production variability. The coefficient of variation in net income is the usual way to measure production variability. Deviations below a target income level is an attractive alternative.

Classifying a given technology by these five criteria will make it possible to understand reasons for differential adoption rates by farms of different sizes. It will also indicate what additional survey information may be important to collect. For example, adoption rates of a cost-reducing technology would logically not be influenced by credit availability, but a complex technology may be greatly influenced by the farmer's education, experience, and contacts with information sources.

## Analytical Considerations

An excellent discussion of appropriate statistical models for technology adoption studies is given by Feder, Just, and Zilberman. For some technologies a dichotomous "adoption" or "nonadoption" dependent variable may be appropriate. However, in most cases the extent of adoption can also be measured and often is the major question of interest.

The appropriate statistical models for dichotomous dependent variables are the logit and the probit models. The logit model uses a logistic distribution function, and the probit model assumes a normal distribution. These models specify a functional relation between the probability of adoption and various explanatory variables.

The extent of adoption is usually measured as the percentage of land or animals on which the new technology is used. For adoption studies where there are a sizeable number of nonadopters and adopters of varying intensity, a two-stage investigation is appropriate. The first stage looks at the probability of adoption using a dichotomous choice model such as logit. The quantity of use, given adoption, is analyzed in a second step. The tobit model is an analytical tool that explicitly considers the limited nature of the dependent variable.

## Empirical Studies

Two technologies that we selected for study were (1) Poast Herbicide on sugarbeets and (2) computers.

### Poast Herbicide

Poast is a postemergence herbicide that controls grass weeds in sugarbeets. The herbicide was approved for release by EPA for the 1984 crop. Poast gives more effective weed control and causes less sugarbeet injury than previously available grass control herbicides (Dexter). The cost of Poast per acre treated is approximately one-third that of alternative grass control herbicides.

Poast is a divisible, simple, capital-saving technology. It has little or no effect on labor or production variability. Based on this classification one would hypothesize that the technology should be completely size neutral. Adoption of Poast herbicide, therefore, provides an excellent test of the effect of farm size where there are virtually no characteristics of the technology favoring adoption by larger farms.

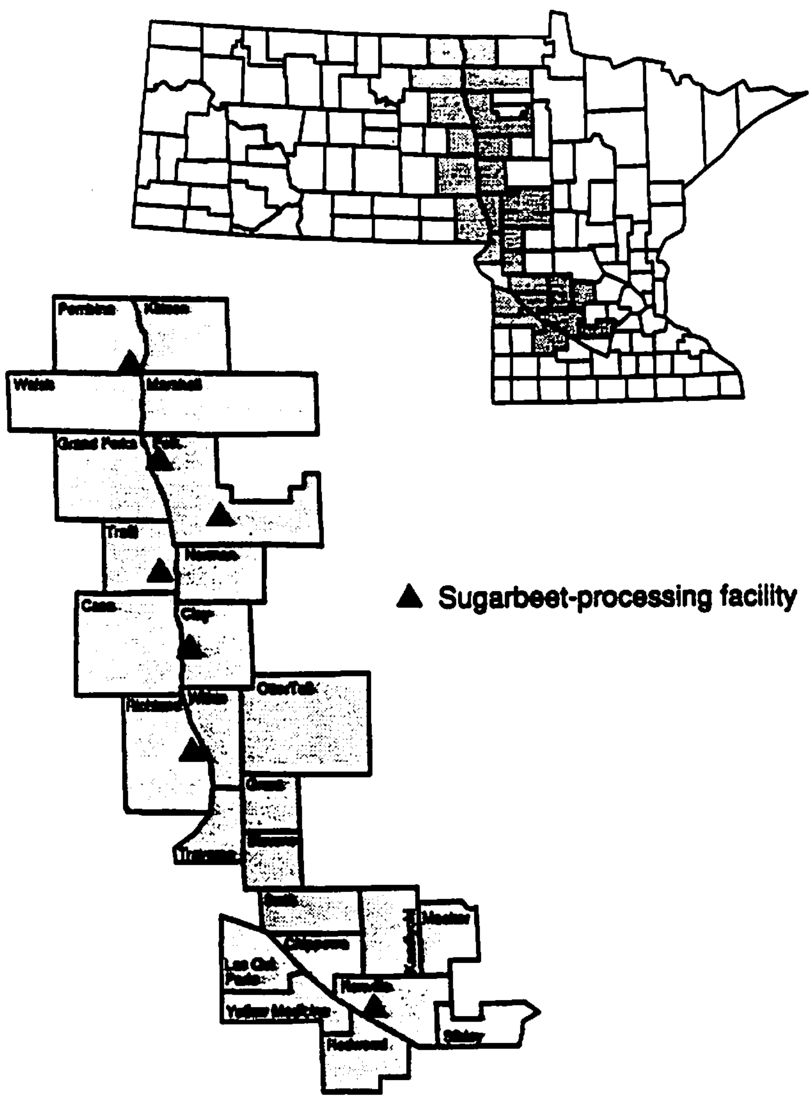
The data set consists of the results of an annual mail survey of sugarbeet herbicide usage conducted by the Extension Sugarbeet Specialists for North Dakota and Minnesota. The survey was mailed to approximately 2,200 sugarbeet producers in North Dakota and Minnesota. The response rate averaged 32 percent over the four years analyzed.

The dependent variable was the percentage of Poast-treated sugarbeet acres. Acres sprayed with Poast or a Poast-blend herbicide were divided by all acres treated with a grass control herbicide to arrive at the percentage treated with Poast.

Independent variables were acres of sugarbeets and dummy variables that represent geographic area. Acres of sugarbeets were used as the measure of farm size. Sugarbeet growers plant from one-fifth to one-third of their cropped land to sugarbeets and receive from one-half to two-thirds of their gross income from this crop. The average sugarbeet producer in the region has 222 acres of sugarbeets out of a total of 1,055 acres in crops (Clauson and Hoff, p. 7).

Three cooperatives process sugarbeets in seven factories in the region (figure 1). American Crystal Sugar Company has five factories in the Red River Valley at approximately 40-mile intervals from the Canadian border to Moorhead (Clay County), Minnesota. Minn-Dak Farmers Coop operates a plant in Wahpeton (Richland County), North Dakota, at the southern extreme of the Red River Valley. Southern Minnesota Beet Sugar Cooperative has a plant at Renville, Minnesota, in southwest-central Minnesota.

The producing region was divided into four areas. The American Crystal growers were divided into north and south areas because of the large geographic area covered. Separate areas were established for Minn-Dak and Southern Minnesota growers. Factory ownership was important because the cooperatives work closely with farmers to assure production of high quality sugarbeets. Each factory has a group of fieldmen who each work with 50 to 70 producers.




SOURCE: N.D. Agricultural Statistics (1987); Minn. Agricultural Statistics (1987).

Figure 1. Counties producing sugarbeets with growers affiliated with the three sugar-processing cooperatives.

The mean rate of adoption by year and farm size is summarized in Figure 2. Adoption in the initial year was less than 20 percent and increased to over 60 percent in the fourth year.

The data were analyzed using the Heckman approach to the tobit model (Kmenta, p.563). No significant differences were found in intercept or slope parameters between northern and southern American Crystal growers. The Minn-Dak and Southern Minnesota growers, however, had significantly different adoption size relationships.

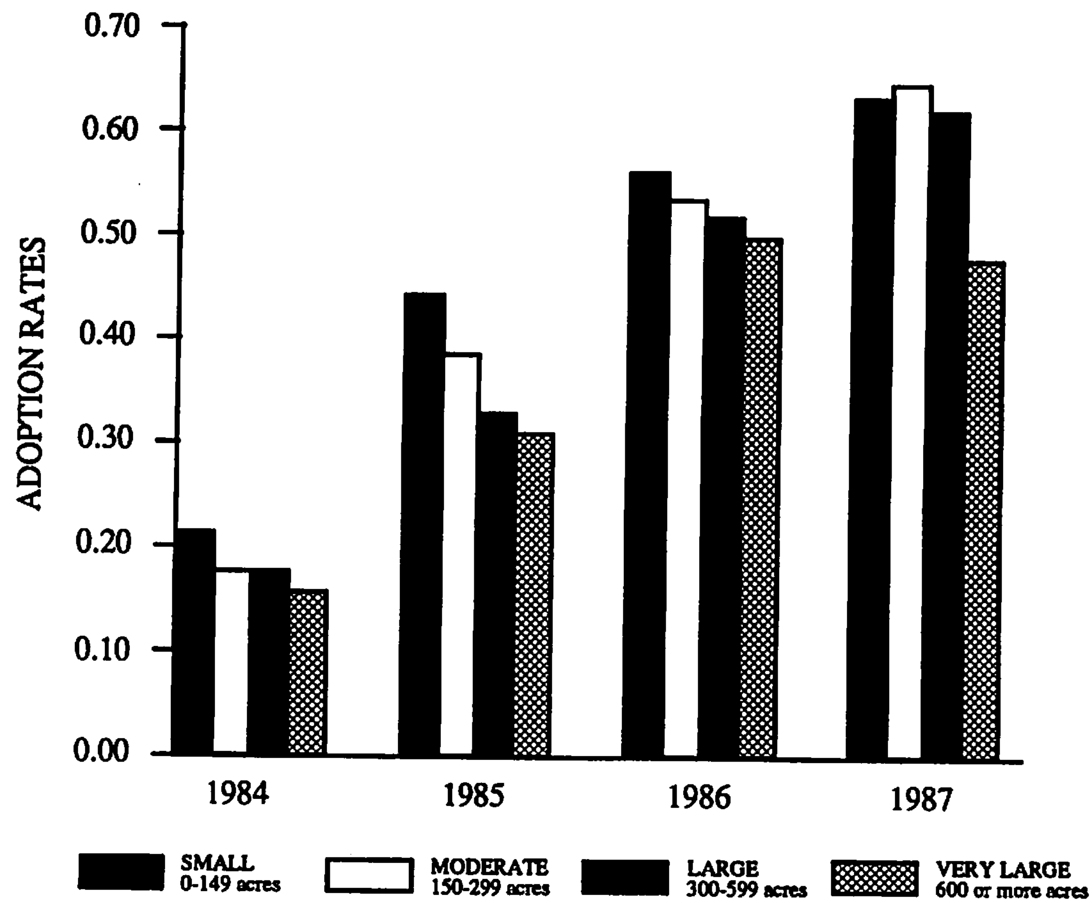



Figure 2. Adoption for Poast Herbicide Mixes by Year and Acres of Sugarbeets

Separate models were run for each year to determine if the acreage adoption relationship changed with the passage of time. There was a statistically (1% level) significant slope shift for Minn-Dak growers in 1986 and 1987 from the first two years. Based on these results, a pooled years-area model was developed. The variables in the pooled model were year, cooperative area, acres, and year-acres interaction for Minn-Dak. The relationships between adoption and farm size in sugarbeet acres for the three grower areas are summarized in Table 1.

TABLE 1. POOLED TOBIT MODEL RELATIONSHIPS BETWEEN POAST HERBICIDE USE AND SUGARBEET ACRES FOR THREE AREAS IN NORTH DAKOTA AND MINNESOTA 1984-1987

| | Variable | Parameter | Two Tailed T-Statistic[a] |
|---|---|---|---|
| American Crystal Growers | acres | $-30.7 \times 10^{-5}$ | 3.28 |
| Minn-Dak Growers | acres | $50.7 \times 10^{-5}$ | 1.86 |
| 1986-87 Slope Shift | | $-92.9 \times 10^{-5}$ | -2.83 |
| Southern Minnesota Growers | acres | $18.9 \times 10^{-5}$ | 2.03 |

[a]t( 1%) = 2.58, t( 5%) = 1.96, t(10%) = 1.64

The following conclusions are drawn from the results.

1. Differences in adoption size relationships among company areas and not among geographical areas within a company suggest the importance of the historical and institutional setting over location per se. The American Crystal area has been producing sugarbeets for over 50 years, while the two other cooperatives began production in 1973 and 1974. Fieldman selection, training, and responsibilities also differ among the three cooperatives.

2. The hypothesis of a positive relation between farm size and adoption rate is refuted by the American Crystal results. We know of no other adoption studies showing a statistically significant (1%) negative relationship. Further research seems warranted to try to explain the reason for these results. One hypothesis is that younger and more innovative farmers are the producers with smaller acreage, while the larger-acreage producers tend to be older or second-generation producers who are more tradition oriented.

3. The positive relation of adoption to size for Southern Minnesota producers and Minn-Dak producers in the first two years supports the positive adoption farm size hypothesis found in the literature. These are relatively new producing areas where the production of sugarbeets in itself is considered somewhat innovative. This suggests that for a relatively new crop the adoption rate is positively related to farm size even for a size-neutral type of technology.

4. The shift from a positive to a negative relationship between size and adoption rate was found for the Minn-Dak area. This supports the assertion of Ruttan that smaller farmers adopt slower in the beginning but quickly catch up.

Unfortunately, information on other variables affecting adoption (such as education) were not available to explore in greater depth the reasons of the results obtained.

## Computers

The adoption of computers by farmers was the other technology selected for empirical analysis. The data came from a *Farm Futures Magazine* survey of 102 farmers throughout the United States. This was not a random sample of farmers since the editors drew a sample from their list of subscribers who tend to have larger acreages and perhaps are more progressive farmers.

Computers can be classified as indivisible and complex, with a low to moderate capital requirement. Although computers have the potential to be labor saving, they often increase time required for labor to improve the control and planning aspects of management. Computer use probably has little or no effect on income variability.

Computers are a "continuous" innovation. Continual technical improvements and adaptation to the market have occurred over time, resulting in lower prices, more areas for application, and increasingly user-friendly programs. Early adopters in many cases were leaders in introducing the process but did not accrue "adoption rents," and thus, were followers when it came to profitability. An implicit assumption of this study is that by 1988 computer adoption would be profitable by the commercial-sized farms in the survey.

Thirty-one of the 102 respondents to the survey owned computers. Record keeping and word processing were the most popular uses. A summary of responses to the questionnaire is presented in Table 2.

The mean computer price was $2,489 with a range from $290 to $15,000. The mean price for programs was $790 with a range from zero to $3,700.

The variables analyzed were farm size, age of operator, years of education, enterprise emphasis, and location of the farm. Twelve observations were dropped for the statistical analysis because of missing data.

Gross receipts from crops and livestock were estimated based on acres, farm location, and livestock numbers. Calculated gross receipts were used to measure farm size and to calculate the percent of gross income from crops, hogs, and beef. Dummy variables were developed for five farming regions: Lake States, Corn Belt, Great Plains, the West, and Eastern-Delta States.

TABLE 2. SUMMARY OF COMPUTER OWNERSHIP AND USE--FARM FUTURES MAGAZINE SURVEY, 1988

| Ownership | Number | |
|---|---|---|
| Apple or Macintosh | 9 | 14 owners have hard disks, 7 have modems, mean RAM = 343 |
| IBM | 6 | |
| IBM Compatible | 11 | |
| Other | 5 | |
| Total owners | 31 | |
| Don't own | 71 | (28 plan to purchase in the next 5 years) |
| **Uses of computer by owner** | **Percent** | |
| Bookkeeping & financial statements | 94 | |
| Production records | 68 | |
| Word processing | 65 | |
| Education and games | 61 | |
| Maintenance records | 42 | |
| Family budgeting | 32 | |
| Market information and charting | 26 | |

A logit statistical model was used to identify statistically important variables in predicting the probability of computer ownership. The dummy variables for location were not found to be statistically significant at the 10 percent level and were omitted from the model. The results are summarized in Table 3.

TABLE 3. LOGIT ANALYSIS OF COMPUTER OWNERSHIP--*FARM FUTURES MAGAZINE* COMPUTER SURVEY RESULTS, 1988

| Variable | Parameter Sign | Chi-Square | Sign Level |
|---|---|---|---|
| Age | negative | 1.99 | .157 |
| Education | positive | 8.41 | .003 |
| Gross income | positive | 4.32 | .037 |
| Percent crop | positive | 4.24 | .039 |

Computer owners were asked the frequency of use and time spent using the computer. From this information an estimate of intensity of use in hours per year was calculated. The tobit model was employed to analyze the significance of the same variables analyzed in the logit model. Again, the location variables were not significant. The results are presented in Table 4.

TABLE 4. TOBIT ANALYSIS OF COMPUTER USE--*FARM FUTURES MAGAZINE* SURVEY, 1988

| Variable | T-Statistic | Significance Level |
|---|---|---|
| Age | -1.18 | .21 |
| Education | 3.32 | .01 |
| Gross income | 2.50 | .05 |
| Percent crop | 2.50 | .05 |

Comparison of the characteristics of owners and nonowners of computers using the logit model and intensity of computer use employing the tobit model gave almost identical results. In both analyses the most significant variable was education. Education was measured as years of schooling beyond grade seven. Size as measured by gross income and percent crop income were of about the same significance. Age was negatively related to ownership and use of computers but was not significant at the 10 percent level.

The time and effort involved to efficiently and effectively use computers is high relative to most technological innovations. The high learning cost is greatly reduced if the adopter has received training in computer uses in his or her education. Years of schooling, particularly for younger farmers, increase the likelihood that they would have received some formal training in the use of computers. The greater computer use by crop farmers was somewhat unexpected.

Both the high learning cost and the indivisibility of computer technology argue for a strong relationship with farm size. However, it is likely that recent fairly inexpensive computers and noncopyrighted and less expensive software programs have muted the indivisibility problem for smaller farms by 1988. One can argue that the greatest obstacle now to overcome in adopting computers is the fixed cost of learning about computer technology.

The farm size computer adoption relationship may change over time as computers become less complex, more user-friendly, and less expensive. In addition, through public education in primary, secondary, and post-secondary institutions, computer literacy will become part of the institutional framework into which new computer technology will be introduced.

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