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Factors Influencing the Adoption of Breeding Technologies in U.S. Hog Production

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An important aspect of structural change in the U.S. hog industry has been the adoption of breeding technology. The adoption of each of four breeding technologies, weekly farrowing, intensive breeding, terminal crossbreeding, and artificial insemination, in U.S. hog production is analyzed using multivariate probit analysis. Results suggest that diversification, whether the producer raised breeding stock, debt and asset levels, and producer's education influence adoption rate. Larger, more risk-averse producers were more likely to adopt technology. Producers who rated the quality of labor available as higher were more likely to adopt management-intensive technologies.

Key Words: hog industry, multivariate probit, technology adoption

JEL Classifications: N51, Q12

Economists have attributed the rapidly changing structure of the U.S. hog industry to a number of factors. Perhaps the most important driver of structural change has been the development and adoption of technology.¹ Throughout recent agricultural history, producers have simultaneously adopted new technology and expanded their operations to lower average total cost, thereby benefitting from

economies of size.² As discussed by Reimund, Martin, and Moore and later Gillespie, Karantininis, and Storey, with respect to the hog industry, the adoption of technology has led to increases in farm size, specialization, and associated risks, transaction costs, and asset specificity. The result has been increased vertical coordination in the industry. Breeding technologies have been particularly important, allowing for the timely production of greater numbers of consistent quality hogs with a given set of resources. Evidence of the increase in technical efficiency associated with breeding technologies is shown in the increased pig crop per farrowing sow over the period 1991–2000. In 1991, 15.8 pigs were farrowed per sow in the United States, whereas in 2001, 17.6 pigs were farrowed per sow, amounting to an 11% increase in efficiency.

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¹ For the purpose of this study, technology refers to the input set that is used to produce output. Thus, technology adoption refers to a shift in the input set to produce a given output. Such a shift may involve the adoption of a new machine that radically changes the input set or simply the adoption of a different management strategy that results in a significant shift in the input set.

² In the long run, increased profits have not been sustained as prices eventually fall, according to Cochrane's treadmill theory.

It is useful to examine the rate of adoption of the most important breeding technologies in the industry and the type of producer who has adopted these technologies. Such analysis provides a view of the type of producer who is likely to be involved in hog production in the future as the industry continues to evolve toward larger, more specialized farms. The breeding technologies examined in this paper include weekly farrowing, intensive breeding, terminal crossbreeding, and artificial insemination. Adoption of each of these technologies has influenced the increased pig crop per farrowing sow in recent years. Each, however, differs in terms of the managerial versus capital investment required for adoption. The adoption of effective weekly farrowing requires a substantial capital investment, whereas the adoption of any of the four technologies requires sizeable investment in managerial skills. Thus, although it is expected that many of the producers who adopt one technology also adopt the others, the differences in incentives to adopt each of the technologies likely lead to some differences in adoption rates and types of producers who adopt each.

The objectives of this paper are to determine (1) the extent of adoption of the breeding technologies weekly farrowing, terminal crossbreeding, intensive breeding, and artificial insemination in U.S. hog production; (2) the impact of financial, demographic, and structural variables on the adoption of these technologies; and (3) whether simultaneity of adoption exists among the technologies. Whereas a large number of other technologies has also allowed the hog industry to evolve significantly in recent years (e.g., all-in all-out production, split-sex feeding, etc.), this study focuses on technologies used by the breeding-farrowing segment.

Description of the Technologies Analyzed in This Study

Weekly farrowing involves scheduled matings to ensure weekly production of pigs. This system ensures that hogs are ready for sale weekly, with a continuous supply of hogs flowing through the system year-round. This manage-

ment system is used to ensure the greatest amount of throughput possible within a given physical structure. Thus, its use is likely to increase the technical efficiency of an operation. Weekly farrowing requires at least a minimum size of operation to be cost effective. Jones, Hurt, and Hale discuss the conversion of an existing 150-sow operation to one that includes weekly farrowing and segregated early weaning. Through involvement in a cooperative with other producers, throughput is increased dramatically and costs of production per sow decrease. Requirements may include conversion of some existing facilities to other uses, such as a nursery to a farrowing room; entering into an alternative business arrangement, such as a cooperative agreement with other producers; and increased management requirements.

The term "intensive breeding" is generally used to connote the maximization of litters produced per sow per year. A traditional rule of thumb for producers has been to strive for two litters per sow per year. Intensive breeding systems strive for 2.25 litters per year by checking for heat in sows twice daily, inseminating sows often to ensure pregnancy, and using segregated early weaning. After weaning, the goal is to get the sow to come into heat within 3 to 7 days. Thus, intensive breeding requires close monitoring of sows and, thus, good management.

Terminal crossbreeding refers to the mating of a two-breed single or rotational cross female with a boar of a third breed. One breed of boar is used to sire all pigs, and all pigs are marketed; thus, breeding stock is not raised within the system. All female breeding stock is purchased on the basis of reproductive performance. Crossbreeding is well accepted by commercial pork producers for enhancing productivity through the exploitation of heterosis and breed differences (Kuhlers, Jungst, and Little). Both rotational and terminal crossbreeding systems are commonly used. The major advantage of rotational crossbreeding systems is the production of replacement females within the system. However, three disadvantages are that breed complementarity is not maximized, there is an increase in vari-

ability due to the differences in breed composition through the generations, and 100% heterosis is not realized (Kuhlers, Jungst, and Little). Most three-breed terminal crossbreeding programs are designed to improve each of these dimensions. Kuhlers, Jungst, and Little show that one terminal crossbreeding system resulted in greater backfat thickness and better survival rates from 56 days of age to 100 kg than did a rotational crossbreeding system with similar goals. Johnson and Ruttan state that terminal crossbreeding results in a more rapid rate of genetic improvement than rotational crossbreeding, and suggest that terminal crossbreeding is used by the larger hog producers.

Artificial insemination is among the most cost-effective ways to improve a gene pool. High-quality semen can be purchased without the investment in and expenses associated with owning a boar. Although the costs of artificial insemination service and natural service vary from farm to farm, Singleton and Schinckel suggest that the costs "may be similar." Semen prices vary widely, depending upon the sire. A relatively small initial investment is required since the cost of the equipment required is not great and the techniques are not difficult to learn. The use of artificial insemination does require special training, and the availability of quality labor is important for effective implementation. Thus, the increased management requirements are, perhaps, the greatest obstacles to adoption. The diffusion of artificial insemination in the pork industry has been slower than that of the dairy industry, but its use continues to become more widespread.

There is likely to be complementarity among the four technologies. One would expect their adoption to occur alongside some or all of the others. For instance, use of artificial insemination with intensive breeding allows the producer to insure that the sow is bred at the precise time the producer believes it to be optimal. Singleton and Schinckel cite the implementation of terminal crossbreeding systems as a main concept in improvement of genetics via artificial insemination. Similar arguments can be made for the simultaneity of

adoption among the other technologies. Thus, a multivariate probit analysis is utilized to examine the adoption of the four breeding technologies.

Previous Studies Analyzing the Adoption of Technology

A rich set of literature has examined the nature of technology adoption over time and the factors that have influenced the speed of adoption. Among the earlier studies was Griliches' analysis of the adoption of hybrid corn in the United States, which showed its adoption over time following an S-shaped curve. At least two extensive reviews of literature have been conducted over technology adoption studies and conclusions drawn as to what is known and what is to be learned from such studies. Feder, Just, and Zilberman covered literature through the late 1970s on the adoption of technology in developing countries, and Marra and Carlson covered literature dealing with risk and its impact on technology adoption.

Among the conclusions and implications for further adoption research presented by Feder, Just, and Zilberman were that adoption decisions for various technologies were often interrelated and that the complementarities should be considered simultaneously using appropriate econometric procedures. Since their study, several studies have attempted to examine the simultaneous adoption of technologies. Smale and Heisey examined the adoption of improved seed varieties along with fertilizer intensity using a two-stage tobit model in a simultaneous system. Caswell and Zilberman examined the choice among three technologies, including the traditional one, using a multinomial logit model. Factor analysis has also been utilized to group technologies into interrelated sets (Rauniyar and Goode).

The most recent studies examining the simultaneous adoption of more than one technology have utilized multinomial probit analysis. These studies have examined the adoption of two alternative technologies, along with the possibility of adopting neither or both. Both Zepeda and Dorfman have conducted such studies. Dorfman examined the

adoption of improved irrigation techniques and integrated pest management.

Feder, Just, and Zilberman stress the importance of different social, cultural, and institutional environments in the different adoption rates of technology in different regions or countries. Many studies have examined the influence of economic, demographic, and farm characteristic variables on technology adoption. Greater discussion of these studies and others are included in the discussion of the analysis as independent variables in the model are introduced.

Zepeda analyzed factors affecting the adoption of management-intensive versus capital-intensive technologies. The technologies analyzed in the present study can be argued to be more management-intensive than capital-intensive in nature. It is, however, noted that successful adoption of some management-intensive technologies, such as weekly farrowing, requires substantial capital investment. Thus, such technologies can also be argued to have characteristics of capital-intensive technologies.

The present study differs from previous studies in the following ways. First, this study addresses the adoption of livestock breeding technology, which has been an important factor influencing sow productivity and, ultimately, industry structural change. Second, the adoption decisions are modeled in a multivariate probit framework that allows for increased efficiency in estimation in the case of simultaneity of adoption.

Data and Methods

During July–September, 2000, surveys were sent to 4,986 U.S. hog producers via mail to determine whether they had adopted each of the four technologies. The sample was randomly drawn from across the United States. Producer names had been obtained through a subscription list of *National Hog Farmer* magazine. Of these, 1,025 producers responded with completed surveys. Considering the respondents who informed us they were no longer in business, this is a 22% return rate. Dillman's approach to mail surveying was

used as a guide in designing and implementing the survey. Producers were first sent a mailing with a letter explaining the importance of the study and a survey. A follow-up postcard reminder was sent 2 weeks later. A third mailing with a second letter and a survey was then sent to the nonrespondents. The survey group was a stratified sample of U.S. hog producers with 831 producers in each of the following hog inventory size categories: 200–999 hogs, 1,000–1,999 hogs, 2,000–2,999 hogs, 3,000–4,999 hogs, 5,000–9,999 hogs, and 10,000 hogs and over. The U.S. Department of Agriculture National Agricultural Statistics Service (USDA-NASS) reports that in 1999, 52,730 producers had 1–99 hogs, 32,105 had 100–999 hogs, 6,500 had 1,000–1,999 hogs, 5,120 had 2,000–4,999 hogs, and 2,005 had over 5,000 head in inventory. Thus, while the subgroups of producers should represent the producers in their respective categories, the group as a whole cannot be considered as representative of the entire hog producer population.

Producers were asked to indicate which of the following technologies they currently used: terminal crossbreeding, intensive breeding, artificial insemination, and weekly farrowing. Only the producers who had sows in their operations were analyzed in the breeding technology analysis.

A multivariate probit model is used to estimate the impact of demographic, economic, and behavioral variables on the adoption of four breeding technologies. This simultaneous equations system provides more efficient estimates when contemporaneous correlation is present. As discussed previously, other studies (e.g., Zepeda and Dorfman) have used multinomial probit to analyze the adoption of two alternative technologies. However, use of the multinomial probit becomes complicated when more than two technologies are to be analyzed; for example, with three or four technologies, there would be eight or 15 choices, respectively, to be considered. Such models become difficult, if not impossible, to estimate in a practical setting. To account for the contemporaneous correlation of the error terms across three or more individual binomial probit adoption equations, the multivariate probit

model may be used. Such a model does not allow for the computation of the probability of adoption of more than one technology at a time, but does account for contemporaneous correlation and reduces bias.

Bivariate probit analysis has been used with some success and, in principle, the multivariate model could be estimated by simply adding equations to the system. Multivariate probit models estimated in this way have not provided efficient and accurate results due to the evaluation of higher-order multivariate normal integrals (Greene 2000). However, recent developments have reduced the obstacles to evaluating multivariate normal integrals. The reader is referred to Greene (2000) as well as articles by Chib and Greenburg and Bock and Gibbons for further discussion of this subject. The general formulation of the multivariate probit model is:

$$(1) \quad y_{im}^* = \beta_m' X_{im} + \varepsilon_{im}, \quad m = 1, \dots, M$$

$$y_{im} = \begin{cases} 1 & \text{if } y_{im}^* > 0, \text{ and} \\ 0 & \text{otherwise,} \end{cases}$$

where $\varepsilon, m = 1, \dots, M$ have a multivariate normal distribution with mean vector 0 and covariance matrix R with diagonal elements equal to 1. Probabilities in the model are computed using the Geweke-Hajivassiliou-Keane simulator, which produces approximations to the M -fold integral:

$$(2) \quad P = \int_{A(M)} \dots \int_{A(1)}^{B(1)} f(x_1, \dots, x_M) dx_1, \dots, dx_M,$$

where $f(\cdot)$ is the M -variate normal density of x with mean vector 0 and $M \times M$ positive definite covariance W . The log likelihood for the model is accumulated as the sum of the logs of the probabilities of the observed outcomes (Greene 1998):

$$(3) \quad \Pr(y_1, \dots, y_M | x_1, \dots, x_M) = MVN(Tz, TRT'),$$

where z is the vector of utilities, $z_m = \beta_m' x_{im}$, R is the correlation matrix, T is a diagonal matrix with $t_{mm} = 2y_m - 1$, and MVN specifies "multivariate normal." In this study, an equa-

tion is estimated for each of the four technologies and contemporaneous correlation is tested. Since the analysis uses a stratified sample, data was weighted in the analysis according to stratification. Because our size categories did not correspond with those utilized by USDA-NASS, weights were determined according to the percentages of the *National Hog Farmer* subscription list included in each stratification.

Independent Variables Considered in the Analysis

The following independent variables are used in each of the analyses of adoption of technology. *Southeastern U.S.* is a dummy variable indicating that the farm is located in one of the following 11 states: Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Texas, or Virginia. The Southeast is second only to the Midwest in U.S. hog production; its structure has changed rapidly in recent years with states such as Arkansas, Mississippi, and North Carolina gaining significantly in hog numbers. This variable allows for determination of whether technology adoption in the breeding segment has changed accordingly.

Number of sows in the operation was used to examine the influence of farm size on technology adoption. The variable was rescaled by dividing by 10 for estimation purposes (*Sows/10*). Farm size has been shown in a number of studies to be associated with technology adoption, with Perrin and Winkleman (1976) making a sound argument for this. *Number of Sows* is a continuous variable indicating the number of breeding sows in the operation. It is hypothesized that, as the number of sows increases, the adoption rates for each of the technologies increases. Weekly farrowing cannot be accomplished without at least a minimum number of sows. Foster, Hurt, and Hale (1995) design and compare four alternative high-technology farrow-to-finish farms, with 150, 300, 600, and 1,200 sows each. They assume weekly farrowing only in the larger three units, as the 150-sow unit could farrow only six to eight sows weekly. Although the other three technologies do not necessarily require

large numbers of sows to implement and may, in fact, be scale neutral, it is likely to be the larger, efficiency-minded producers who conduct them. Johnson and Ruttan state that, "Most large farms use terminal crossbreeding, which maximizes output per animal. . . ." When considering learning and managerial expenses associated with each as being appropriated as fixed expenses, this would discourage adoption by smaller farmers.

Number of Other Enterprises is a continuous variable indicating the number of agricultural enterprises other than hogs that are being raised on the farm. It is expected that the more specialized producers are the most likely adopters of technology. Involvement in other enterprises requires management and labor with the other enterprises, which is likely to reduce the time available for involvement in management-intensive technologies in the hog industry, such as those analyzed here. Thus, the producer's span of control may limit extensive technology adoption in any of the enterprises. Fernandez-Cornejo, Beach, and Huang found lower adoption of integrated pest management among vegetable growers when producers were also engaged in livestock production. *Percentage of Income Off-Farm*, which indicates the percentage of household income coming from off-farm sources, is also expected to be negatively associated with the adoption of the technologies, for the same reasons as *Number of Other Enterprises*. An alternative argument that has been made in other studies, as discussed in Feder, Just, and Zilberman, is that off-farm income can increase the probability of adoption since working capital is less likely to be constrained. This seems to be more likely the case with capital-intensive than management-intensive technologies.

Producer Holds No Debt is a dummy variable indicating that the farmer holds no debt on his or her farm operation.³ It is expected that debt-free producers are generally either low-input producers or producers who are

nearing retirement and are not motivated to adopt new technology. Several studies have discussed the role of the credit constraint in curbing adoption of technology, as discussed by Feder, Just, and Zilberman. Whereas low- or no-debt operations likely have greater opportunity to adopt technology, an ex-post analysis of adoption is likely to show that technology adopters have incurred debt to finance enterprise expansion and technology adoption. Each of the technologies analyzed in this study require some initial capital investment, though weekly farrowing is the only one that is likely to require a major investment, since it may require expansion of the operation.

Producer Is Under Contract is a dummy variable that indicates that the operator is under contract with a firm that provides many of the variable inputs such as livestock, feed, veterinary services, and medication, while the operator provides labor, utilities, fuel, and fixed inputs. The operator is paid by the contractor on the basis of productivity. Relatively few farrowing operations are under contract, as contract operations are more likely to be finishing operations. It is, however, hypothesized that producers under contract will more readily adopt technology than those who are not under contract. This is due to the contractor's requirement that such technology be adopted and the relatively lower initial investment required of contract producers to enter hog production. Contractors are likely to require state-of-the-art facilities that increase the homogeneity of product produced and maximize production efficiency. Each of the technologies examined here contribute to greater product homogeneity or greater production efficiency, or both. Since contract producers generally do not make the initial investment in breeding stock, feed, and other inputs, the credit constraint is less likely to be binding in adopting technology.

Farm Assets $\geq \$1.5$ Million is a dummy variable that indicates that the value of the operator's total farm assets is greater than or equal to \$1.5 million. This variable measures the overall farm size, not specifically the size of the hog enterprise. For the same reasons that greater farm size is likely to be positively

³ The debt-asset ratio was originally included in the model as a continuous variable, but was not found to be significantly associated with the adoption of any of the technologies.

related with adoption, it is expected that this variable will be positively associated with technology adoption, as producers with greater assets are likely to have the resources available to adopt new technology.

Labor Quality Rating is a continuous variable that indicates the quality of labor available to the operator. The question in the survey reads as follows: "On a scale of 0 to 10, how would you rate the quality of labor available to assist in your production unit(s)?" Thus, this variable measures the producer's perception of the quality of labor available. The authors were unable to identify other studies that have attempted to address labor quality, though labor availability has been discussed as important in technology adoption. Given the management-intensive nature of each of these technologies, it is expected that this variable will have a positive sign, as labor quality is highly important in cases where the producer cannot conduct the tasks himself or herself. Intensive breeding requires close monitoring of sows to ensure timely breeding. Both terminal crossbreeding and artificial insemination require training, increasing the need for quality labor.

Producer's Age is a continuous variable indicating the age of the respondent. Generally, it is expected that younger producers have longer planning horizons and, thus, are more likely to adopt technologies that require substantial capital investment. In the case of these management-intensive technologies, the initial capital investment associated with each technology may not be excessive if facilities are already in place. Thus, the planning horizon argument may be less likely valid for these technologies than some others. However, also important in technology adoption is the stage of the life cycle of the producer. Boehlje discusses the sociological model of family farm structure, where the exit or disinvestment stage is the third and final stage. In this stage, producers generally attempt to reduce managerial responsibilities while continuing to maintain the level of operation that will generate adequate retirement income. The reduction in managerial responsibilities is likely to be in conflict with the adoption of any of the

technologies examined in this study. It is hypothesized that older producers are less likely to switch from a practice that has proven to be profitable than younger ones; thus, a negative sign is expected for each equation. The adoption of technology with the short-term uncertainty associated with learning how to successfully implement a new production strategy is less likely to occur. Anderson, Wilson, and Thompson found that adoption of level fields and basins decreased with age.

Producer Has College Degree is a dummy variable that indicates that the respondent has a college Bachelor's degree. It is expected that producers with a 4-year college degree are more likely to adopt each of the technologies than those without the degree. Education is expected to increase the ability to successfully implement management-intensive technologies, thus the positive sign. Though many studies have shown positive relationships between education and the adoption of technology, several more recent studies include Marra, Hubbell, and Carlson with respect to the adoption of Bt Cotton, Soule with respect to the adoption of conservation tillage and strip cropping in corn production, and Cardona with respect to adoption of best management practices in sugarcane production. Zepeda found that education was positively related with adoption of management-intensive technology, but found no relationship with the adoption of capital-intensive technology.

Producer Is Risk Averse is a dummy variable indicating that the producer considers himself or herself risk averse. It is the result of the following question: "Relative to other investors, how would you characterize yourself?" Possible answers include: "I tend to take on substantial levels of risk in my investment decisions, I tend to avoid risk when possible in my investment decisions, and I neither seek nor avoid risk in my investment decisions." This question was used as a proxy for risk preference, as suggested by results of Fausti and Gillespie. A wealth of literature has examined the impact of risk preference on the adoption of technology (e.g., Feder), with the most recent work by Marra and Carlson. It is expected that risk-averse producers will be

Table 1. Adoption of Breeding Technologies by 525 U.S. Hog Producers Who Were Involved in Farrowing Pigs

Size Category	All Sizes	200–999	1,000–	2,000–	3,000–	5,000–	≥10,000
		Hogs	1,999 Hogs	2,999 Hogs	4,999 Hogs	9,999 Hogs	
Number							
Weekly Farrowing	193	8	9	18	40	66	52
Intensive Breeding	264	20	30	33	53	77	51
Terminal Crossbreeding	296	26	33	57	62	71	47
Artificial Insemination	260	20	31	36	56	68	49
Percentage							
Weekly Farrowing		8.8	10.6	18.8	41.2	71.0	81.3
Intensive Breeding		22.0	35.3	34.4	54.6	82.8	79.7
Terminal Crossbreeding		28.6	38.8	59.4	63.9	76.3	73.4
Artificial Insemination		22.0	36.5	37.5	57.7	73.1	76.6

more willing to adopt each of these technologies. Weekly farrowing results in weekly sales, arguably reducing price risk. Comparing this with the opposite extreme, the producer who sells twice per year is subject to the market price at two points during the year. In examining market prices over time, one notices the often unexpected reduction or rise in price during a particular week or month. If such a reduction occurs during the month that hogs must be sold, then the producer's annual income from the enterprise can be significantly influenced. The weekly selling of hogs allows the producer to sell during both high and low price periods. Intensive breeding maximizes the throughput of fixed facilities through close monitoring of sows, reducing the possibility of a sow not being bred and, thus, reducing production risk. Artificial insemination also allows the producer to better control the breeding of animals, thus reducing risk.

Breeding Stock Is Raised indicates that the producer raises breeding stock for sale. It is expected that these producers are more likely to utilize artificial insemination to improve the quality of their breeding stock. It is hypothesized, however, that breeders are less likely than commercial operators to adopt weekly farrowing since the focus of the operation is to produce high-quality breeding stock to be sold at premium prices, rather than a large quantity of hogs to be raised for slaughter.

Results

Proportion of the Sample Using Each of the Practices

Table 1 presents results showing the numbers of producers using each of the technologies. Since this is a stratified sample with a higher percentage of large producers than actually exists in the industry, results are presented by size category. The percentages of producers adopting each of the technologies increased with size, with only 8.8% of the producers producing 200–999 hogs reporting weekly farrowing, whereas 81.3% of the ≥10,000 hog producers farrowed weekly. Intensive breeding was used by 22% of 200–999 hog producers and 79.7% of the ≥10,000 producers. Terminal crossbreeding was used by 28.6% of the 200–999 hog producers and 73.4% of the ≥10,000 hog producers. Artificial insemination was used by 22% of the 200–999 hog producers and 76.6% of the ≥10,000 hog producers.

Results of the Multivariate Probit Analysis

Table 2 presents the descriptive statistics of each of the independent variables used in the analysis. Examination of Pearson correlation coefficients, variance inflation factors, and condition indices indicated no serious prob-

Table 2. Descriptive Statistics of Variables

Variable	Units	Mean	Standard Deviation	Minimum	Maximum
Southeastern U.S.	0-1	0.06286	0.24294	0	1
No. of Other Enterprises	Number	3.33206	1.73823	0	10
Labor Quality Rating	0-10	6.00405	2.64613	0	10
Producer Holds No Debt	0-1	0.24762	0.43204	0	1
Producer is under Contract	0-1	0.06667	0.24968	0	1
Farm Assets >\$1.5 Million	0-1	0.28190	0.45036	0	1
Producer's Age	Years	47.39306	12.06592	18	85
Producer Has 4-yr Degree	0-1	0.29714	0.45744	0	1
Producer is Risk Averse	0-1	0.38095	0.48608	0	1
Breeding Stock is Raised	0-1	0.09524	0.29382	0	1
Number of Sows/10	No./10	33.63760	81.36427	1	1000
Percentage Income Off-Farm	%	14.50382	27.76055	0	100

lems with multicollinearity, despite the presence of two variables (*Farm Assets* $\geq$ \$1.5 Million and *Sows/10*) that provided different measurements of operation size.

Examination of correlation coefficients across equations allows for measurement of the correlation between disturbances in the equations, or "the correlation between the outcomes after the influence of the included factors is accounted for" (Greene 2000, p. 854). As shown in Table 3, five of the six correlation coefficients are significant at the 1% probability level, supporting the hypothesis that the error terms across these technologies are correlated. Results indicate that, with 525 observations, 91 iterations were completed with 450 replications, and the log likelihood function was -1,148.424. Table 4 presents results of the effect of independent variables on the adoption of technology.

Variables significant in the weekly farrow-

ing equation include *Number of Other Enterprises*, *Producer Holds No Debt*, *Farm Assets* $\geq$ \$1.5 Million, *Producer Is Risk Averse*, and *Breeding Stock Is Raised*. As expected, producers with more diversified operations were less likely to adopt, as were those who held no debt on their farm operations, or those who were breeders. Producers with greater farm asset value were more likely to adopt weekly farrowing, as were risk-averse producers. Thus, the producers who adopted weekly farrowing were the larger, less diversified producers with greater farm asset value. Weekly farrowing was adopted by the producers who considered themselves to be risk averse.

Variables significant in the intensive breeding equation include *Labor Quality Rating*, *Farm Assets* $\geq$ \$1.5 Million, and *Sows/10*. Producers who considered the quality of labor available to them to be higher were more likely to adopt intensive breeding, as were pro-

Table 3. Results of the Multivariate Probit Model of Adoption of Breeding Technologies in the U.S. Hog Industry: Correlation Coefficients

Equations	Coefficient	Standard Error	Probability
Weekly Farrowing and Intensive Breeding	0.5271***	0.0677	0.0000
Weekly Farrowing and Terminal Crossbreeding	0.1426	0.0898	0.1121
Intensive Breeding and Terminal Crossbreeding	0.2902***	0.0744	0.0001
Weekly Farrowing and Artificial Insemination	0.2451***	0.0877	0.0052
Intensive Breeding and Artificial Insemination	0.5153***	0.0645	0.0000
Terminal Crossbreeding and Artificial Insemination	0.5035***	0.0654	0.0000

Note: *** indicates the variable is significant at the 0.01 level.

Table 4. Results of the Multivariate Probit Model of Adoption of Breeding Technologies in the U.S. Hog Industry

Variable	Weekly Farrowing	Intensive Breeding	Terminal Crossbreeding	Artificial Insemination
Constant	-0.5637** (0.2222)	-0.0517 (0.2132)	-0.0819 (0.1830)	-0.4487** (0.1818)
Southeastern U.S.	0.4464 (0.3171)	-0.4025 (0.2666)	0.0015 (0.2780)	0.0372 (0.2463)
No. of Other Enterprises	-0.1159*** (0.0423)	-0.0551 (0.0378)	-0.0047 (0.0343)	0.0010 (0.0060)
Labor Quality Rating	0.0006 (0.0004)	0.0011** (0.0005)	0.0013*** (0.0004)	0.0011** (0.0004)
Producer Holds No Debt	-0.5166*** (0.1742)	-0.1258 (0.1514)	-0.4525*** (0.1465)	-0.0853 (0.1495)
Producer is under Contract	0.1526 (0.3139)	-0.1769 (0.3338)	-0.4136 (0.2680)	0.1855 (0.2987)
Farm Assets >\$1.5 Million	1.0877*** (0.1652)	0.4727*** (0.1618)	0.6028*** (0.1464)	0.2915* (0.1517)
Producer's Age	-0.0006 (0.0023)	-0.0005 (0.0026)	-0.0004 (0.0022)	-0.0001 (0.0031)
College Degree	0.2024 (0.1473)	0.0094 (0.1376)	0.1854 (0.1301)	0.5892*** (0.1331)
Producer is Risk Averse	0.2860** (0.1444)	-0.0851 (0.1315)	0.1164 (0.1224)	-0.1087 (0.1302)
Breeding Stock is Raised	-0.5905* (0.3151)	-0.0131 (0.2256)	-0.1618 (0.2376)	0.1561 (0.2242)
Sows/10	0.0031 (0.0022)	0.0041** (0.0020)	0.0001 (0.0001)	0.0025 (0.0015)
Percentage Income Off-Farm	0.0012 (0.0022)	0.0009 (0.0021)	0.0008 (0.0021)	0.0014 (0.0021)

Notes: *** indicates the variable is significant at the 0.01 level; ** indicates the variable is significant at the 0.05 level; and * indicates the variable is significant at the 0.10 level. Numbers in parentheses are standard errors.

ducers who had higher levels of farm assets. *Sows/10* was positive and significant, indicating that the larger hog operations were more likely to be involved in intensive breeding. Intensive breeding was adopted by the larger producers who considered the quality of available labor to be higher.

Variables significant in the terminal crossbreeding analysis were *Labor Quality Rating*, *Producer Holds No Debt*, and *Farm Assets > \$1.5 Million*. Again, producers who considered the labor available to them to be of higher quality were more likely to adopt this management-intensive technology. Producers holding no debt were less likely to adopt terminal crossbreeding, and those with higher levels of assets were more likely to adopt the technology.

Variables significant in the artificial insemination analysis include *Labor Quality Rating*, *College Degree*, and *Assets ≥ \$1.5 Million*. Producers who rated the quality of available labor as higher were more likely to adopt artificial insemination, as were those who had a college degree or greater assets.

Discussion

Breeding technologies are a subset of a number of important technologies that have influenced structural change in the U.S. hog industry. Their implementation has been largely responsible for the significant increase in sow productivity that has occurred over the past several decades. Adoption of these technologies is dependent upon a number of factors,

including whether the technology is management or capital intensive, as well as the goals of the producer. The model utilized in this study allowed us to analyze whether there was simultaneity of adoption of the technologies. Although the multivariate probit analysis allowed us to consider these factors, such models continue to present computational challenges, as achieving convergence is sometimes difficult.

Results of the analyses indicate that operation size was a factor in the adoption of each of the technologies, as measured by the numbers of sows, as well as the total farm assets available to the producer. This is as expected, on the basis of both the ability and incentive of the larger farmer to adopt technology. For some technologies, a farmer must be of at least a minimum size to effectively implement; however, another factor influencing technology adoption is the goal structure of producers. Although the authors are unaware of studies conducted on the goal structure of hog producers, a study evaluating the goal hierarchies of dairy and beef cattle producers indicates that larger producers are much more oriented toward profit maximization, as well as other financial goals, than are smaller producers (Basarir). Thus, such producers would be expected to more likely adopt technologies that improve their financial situations than would smaller producers who place more emphasis on other goals such as conservation, family, and leisure goals.

Related to the size of the operation was the number of other enterprises on the farm. As the number of other enterprises increased, the adoption of weekly farrowing decreased. With a limited span of control, the addition of more enterprises disallows the producer to adopt technologies that are particularly size dependent, such as weekly farrowing. Examination of Table 1 shows the range of adoption rates across sizes with weekly farrowing having the greatest range of all of the technologies. We are suggesting that this technology is more size dependent and that hog operation size prevents extensive diversification because of the limited span of control of the operator. Further

research might more thoroughly examine the relations of these factors.

Labor quality had a positive sign and was significant for three of the technologies: intensive breeding, terminal crossbreeding, and artificial insemination. Each of these technologies is both management and labor intensive. Thus, these results underscore the importance of having a skilled workforce available for the adoption of management- and labor-intensive technology. Perhaps even more interesting is that, as the structure of agricultural production continues to advance toward more specialized, intensive production, the demand for quality skilled labor will continue to increase, raising the demand for educational programs to train labor for specific production tasks. This also has important implications for states (or nations) that wish to increase hog production using large-scale operations. States that have devoted limited resources to education need to recognize that many jobs that were previously classified as unskilled labor are requiring greater training than in the past. Related to the labor quality variable, but from the management standpoint, was the college degree variable. This variable was significant for only one technology, artificial insemination. Results do, however, underscore the importance of education in the management of technology.

Of the technologies considered in this analysis, all have been used for extended periods in the industry; thus, the uncertainty associated with using a brand new technology has been reduced. The insignificance of risk preference with respect to two of the management-intensive technologies, intensive breeding and artificial insemination, is not too surprising, given the likely alternative motivations that influence their adoption. It is of interest, however, that the weekly farrowing variable was significant, given the risk-reducing benefits associated with spreading sales at shorter intervals over a time period. Admittedly, however, one must be somewhat cautious with placing too much credence on one generalized measure of risk preference, as discussed by Fausti and Gillespie with respect to the elicitation of risk preferences in a mail survey context.

Two variables that were not significant in

any of the analyses surprised the authors. These included age and hours per week the producer worked in an off-farm job. With respect to the off-farm job variable, the new industry structure includes many producers with large, specialized operations who also hold off-farm jobs. This raises the question of whether off-farm work continues to be a good indicator of technology adoption or operation size, for that matter.

To predict the future adoption rates of these technologies, one must consider the rapid rate of change in farm size in the hog industry. Hog farms continue to increase in size at a rapid rate, as discussed and analyzed by Gillespie and Fulton. Over a 6-year period from 1994 to 2001, the U.S. inventory of hogs remained relatively stable, from 59.9 million to 59.8 million, but the number of hog operations decreased from 207,980 to 80,880. Thus, the average number of hogs per farm more than doubled from 288 to 739. Given the underscored importance of farm size in the adoption of the four technologies analyzed in this study, continued rapid increases in technology adoption should be expected as hog operations increase in size.

[Received December 2001; Accepted July 2003.]

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