Heterogeneous Production Efficiency of Specialized Swine Producers

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Abstract

This research evaluates the efficiency of swine firms differing by specialization type and employed technologies. Measures of technical, allocative, scale, economic, and overall efficiency are separately and jointly estimated for farrow-to-finish, farrow-to-feeder, feeder-to-finish, farrow-to-weanling, weanling-to-feeder, and mixed operations. Findings confirm appreciable differences in efficiency and causes of efficiency. Results suggest that overall efficiency of farrow-to-finish and farrow-to-weanling operations is on average lower than farrow-to-feeder, feeder-to-finish, and weanling-to-feeder operations. In addition, Tobit models examining how demographic factors, farm type, and input expenses influence efficiency indicate additional variation across firm specializations. This information can help aid in making more appropriate decisions such as producers altering their input mixes or researchers evaluating the existence and implications of firm heterogeneity in an industry.

Key words: efficiency, heteroskedastic Tobit, firm specialization, future anticipation, producer heterogeneity, production technology, returns to scale, swine

Introduction

The swine industry in the US, like much of the agricultural sector in general, has been changing drastically in recent years. Between 1994 and 1999, the number of swine operations fell by over 50% (McBride and Key). The proportion of total market hogs produced from traditional farrow-to-finish operations fell from approximately 65% to less than 38% between 1992 and 1998. This change was coupled with an increase in production by specialized hog operations (as a percentage of total US production) from 22% to 58% (McBride and Key). In addition to changes in production specialization, there are significant locational changes occurring in the industry. Onal, Unnevehr, and Bekric note industry trends for larger, more efficient operations to be shifting from the Midwest to the Southeast. With rapid adjustment throughout the industry comes increased pressure for firms to become more efficient to simply remain in the industry. Two principle questions that arise from these observations are "How does business performance vary among different specialized swine production operations?" and "What factors most impact performance of these specialized firms?" While the implications of these issues are significant for swine producers, policy makers, and others, to our knowledge they have not previously been evaluated in the literature and warrant further investigation.

Research on efficiency of swine producers is in itself limited and has focused on several different issues. Rowland et al. examined input use efficiency for 43 farrow-to-finish operators in Kansas for three sequential years. They found that inefficient farms tend to remain inefficient over time and that there is more variability in technical and allocative efficiency over time than in scale efficiency. In addition, they found overall efficient firms typically produced more pork per litter, fed a higher percentage of their own feed grains, and had lower debt-to-asset ratios.

Boland and Patrick analyzed the economic performance for 60 pork producers (primarily farrow-to-finish operators) across 21 quarters spanning from 1986 to 1991. Feed efficiency and pigs sold per sow had the largest impacts on returns. Consistent with Rowland et al., they found that producer's performance relative to competition tends to be stable over time. Sharma, Leung, and Zalenski compared the use of output-oriented DEA models and stochastic frontier production functions in analyzing technical efficiency of 60 swine producers in Hawaii. They found DEA derived efficiency estimates to be lower and attribute this occurrence to the DEA approach attributing all deviations from the frontier to inefficiency. The authors proceed to suggest that production could be increased by 25-40% if producers operated on the efficient frontier.

Each of these prior studies used regional data with a rather small sample of producers, which may not be representative of the US swine production industry as a whole. In addition, understanding how firm efficiency varies across different swine operation types is a crucial element in accurately comprehending why rapid change is occurring in the swine industry and why firms in various segments of the industry are experiencing mixed business success. Most previous research has not considered the heterogeneity of operation types that exist in the industry. In a sense, this reduces the ability to capture differences that likely exists due to differences in production specialization and employed technologies. This paper seeks to shed light on this by explicitly incorporating organizational structure in an examination of how various swine producing firms operate in their aim to become efficient and survive the recent period of rapid adjustment. Furthermore, this analysis provides an examination of how different operator demographics, size, and firm specialization impact efficiency. In particular, an evaluation of how the number of additional years an operator anticipates producing is provided that has not been previously considered in the literature.

More specifically, technical, allocative, scale, economic, and overall efficiency estimates are developed in this study for different swine production specializations. The firm types considered are "farrow-to-finish," "farrow-to-feeder," "feeder-to-finish," "farrow-to-weanling," "weanling-to-feeder," and "mixed" operations. Furthermore, estimated Tobit models examining factors related to efficiency measures are used to identify factors that are heterogeneous across firms and across organizational structures.

Methods: Firm Efficiency Estimation

Production efficiency has traditionally been examined by either parametric or nonparametric approaches. The parametric approach involves selecting a functional form and estimating the deviation of data observations from the suggested functional form. The nonparametric technique does not require the selection of an underlying functional form. This approach makes relative comparisons with firms within a particular dataset. The nonparametric approach is chosen for this paper and follows that of Banker, Charnes, and Cooper and Färe, Grosskopf, and Lovell.

Relative measures of technical, allocative, scale, economic, and overall efficiency are derived for each individual firm for each different production specialization. To accomplish this, separate linear programming problems are solved for every farm.

Technical Efficiency

Technical efficiency is defined as the ability of a firm to either produce the highest level of output with a set input bundle and technology or to produce the current level of output with the lowest level of inputs. Technical efficiency under variable returns to scale is computed by solving the following linear programming problem for each firm:

$$\begin{aligned}
&Min\ \lambda_i \\
&s.t.:\ \ \mathbf{X'Z} \leq \lambda_i x_i, \\
&\qquad \mathbf{Y'Z} \geq y_i, \\
&\qquad z_1 + z_2 + ... + z_k = 1, \\
&\qquad z_i \in \Re^+
\end{aligned} \tag{1}$$

where λ_i is the measure of technical efficiency for firm *i*, $\mathbf{X'}$ is a matrix of input levels for each producer, x_i is a vector representing the amount of inputs used by firm *i*, $\mathbf{Z}$ is column vector of variable weights, $\mathbf{Y'}$ is a column vector of fixed output amounts, and y_i is the output of firm *i*. Firm *i* is said to be technically efficient (inefficient) if $\lambda_i = 1$ $(\lambda_i < 1)$.

Allocative Efficiency

Allocative efficiency evaluates if a firm is using the optimal bundle of inputs. Allocative efficiency under variable returns to scale is computed by dividing the minimum cost possible by the product of actual cost incurred and technical efficiency (λ_i). The minimum possible cost under variable returns to scale is found using the following linear programming problem for each farm:

$$\begin{aligned}
&C_i^v = Min\ w_i'\tilde{x}_i \\
&s.t.:\ \ \mathbf{X'Z} \leq \tilde{x}_i, \\
&\qquad \mathbf{Y'Z} \geq y_i, \\
&\qquad z_1 + z_2 + ... + z_k = 1 \\
&\qquad z_i \in \Re^+
\end{aligned} \tag{2}$$

where w_i' is a column vector of input prices paid by producer *i* and $\tilde{x}_i$ is a vector of cost-minimizing inputs for producer *i*.

Scale Efficiency

Scale efficiency compares a firm's current operational size with what is most efficient in terms of minimizing average cost. Scale efficiency is calculated as the ratio of minimum possible cost under constant returns to scale (C_i^c) to the minimum cost feasible under variable returns to scale (C_i^v). C_i^c is found using linear programming problem labeled above as (2) without imposing the constraint on the sum of variable weights.

Methods: Profit and Efficiency Explanation Models

Each efficiency measure is bound between zero and one so Tobit models for each organizational group are utilized to examine the relationship that exist between efficiency measures and observed input expenses (per animal unit), size, and selected demographic effects. More formally, the Tobit models were estimated as follows:

$$\begin{aligned} E_i^* &= \beta'\mathbf{X} + e_i \quad , e_i \sim \mathrm{N}[0, \sigma^2] && \text{if } 0 < E_i^* < 1 \\ E_i &= 0 && \text{if } 0 = E_i^* \\ E_i &= 1 && \text{otherwise} \end{aligned} \tag{3}$$

where E_i^* is the measure of firm efficiency, β represents a vector of parameters to be estimated, $\mathbf{X}$ is a vector of explanatory variables, and e_i is a normally distributed error term. The explanatory variables contain input expenditures per animal unit (veterinary, marketing, feed, labor, capital, and miscellaneous), size (entered as the number of animal units), and demographic information (age, education, years experience, and years of anticipated production). The input expenses are on a per animal unit basis in natural log form. Furthermore, in this analysis "years of anticipated production" is included in explanatory models to better account for and understand how operator expectations of the future are related to firm performance.

In addition to estimating the homoskedastic Tobit model, this paper provides a comparison with specifying the model to have a multiplicative heteroskedastic Tobit error term.

If the error term is incorrectly assumed to be homoskedastic, then parameter estimates derived from the homoskedastic Tobit model will be inconsistent. In the context of this paper, an examination is conducted of whether input expenses, firm size, and/or demographic variables contribute to multiplicative heteroskedasticity. More formally, the heteroskedastic Tobit model is specified as in equation (3) with the adjustment that $\sigma_i = \sigma * e^{\gamma' \mathbf{z}_i}$. In this specification, $\mathbf{z}_i$ is a vector of variables (input expenses, size, and demographic variables) being evaluated for generating heteroskedasticity and $\boldsymbol{\gamma}$ is vector of coefficients to be estimated. Here, the model generates estimates for β, σ, and $\boldsymbol{\gamma}$ while the homoskedastic Tobit estimates only β and σ and implicitly assumes $\boldsymbol{\gamma} = 0$.

Data

The *1998 USDA Agricultural Resource Management Survey* of US hog producers is the source of the data for this study. This survey collected detailed information from a cross section of hog operations and was designed to be representative of producers across the US swine industry. The data include a wealth of information including measures of business size, production expenditures, facility use and operation practices, producer demographic information, and financial characteristics.[1]

Summary statistics for each production type, for select variables used, are presented in Table 1. The veterinary, marketing, feed, labor, capital, and miscellaneous variables represent input expenses per animal unit. The animal unit variable is the number of 1,000 pound live weight production on a given farm. Profit is defined as the value of production less total costs and is also expressed per animal unit. Age, education, years experience, and years expected are included to provide supplemental demographic information of those completing the survey. Age

[1] For a more detailed description of the survey see McBride and Key.

and education represent the individual's age (years) and education level. Years experience is a variable capturing the number of years the underlying operation has been producing hogs. Similarly, the years expected variable symbolizes the number of years the operator expects the operation to continue producing hogs.

Examining the summary statistics presented in Table 1 we observe that the typical producer completing the *1998 USDA Agricultural Resource Management Survey* was about 50 years old. While the average age is fairly consistent across firm specialization types, profit, size, education, experience, and planned years of production all vary appreciably. These differences may lead to differences in efficiency and causes of efficiency. To further evaluate if a comparison of efficiency across farm specialization is justified, profit was regressed across firm specialization, input expenses, and demographic factors. As shown in Table 2, farrow-to-weanling operations are the only specialization not found to differ significantly at the 10% level (ceteris paribus) from mixed operations in terms of farm profit.[2] Furthermore, the underlying technology used differs considerably across specializations. Between the noted differences in firm summary statistics, the results of the profit regression, and observed use of heterogeneous technology, it appears that further analysis of efficiency measures across specialization is warranted.

Results

Efficiency Estimates

Table 3 provides a summary of the relative efficiency measures estimated for the entire dataset (1,633 firms) and for each of the 6 subsets representing the different organizational structures.[3] Technical efficiency (TE) averaged 0.66 for the group as a whole with a standard

[2] Mixed operations were omitted (and are the base for comparison) to avoid multicollinearity.
[3] Efficiency estimates for each specialization type were estimated with separate frontiers for each specialization.

deviation of 0.25. This implies that on average, input use could be reduced by 34% if all operations were producing on the frontier. Approximately 19% of the firms (as a whole) were estimated as technically efficient. When comparing this with individual group results, heterogeneity in efficiency estimates becomes evident. For example, the average farrow-to-finish and mixed producers are less efficient (with mean estimates of 0.59 and 0.60, respectively) and the average weanling-to-feeder and farrow-to-feeder operators are notably more efficient (with mean estimates of 0.88 and 0.83, respectively) than those in other specialization categories. The range in mean estimates from 0.59 (farrow-to-finish) to 0.88 (weanling-to-feeder) sheds light on the importance in analyzing firm efficiency based on underlying technologies and not simply considering the swine industry as being homogeneous.

Allocative efficiency (AE) averaged 0.80 for the entire set of firms, with 21% being estimated as efficient. Allocative efficiency was highest (on average) for feeder-to-finish operations which held a mean efficiency estimate of 0.90 (31% estimated as efficient). Conversely, the representative producer in the mixed group had an allocative efficiency estimate of 0.69 (18% being efficient). Scale efficiency (SE) averaged 0.88 across all 1,633 firms (with 43% being estimated as efficient) and had means for subset groups ranging from 0.85 (farrow-to-feeder) to 0.97 (weanling-to-feeder). The mean scale efficiency was higher than mean economic efficiency for each specialization group. This implies that failing to produce at the optimal scale is less of an efficiency issue than failing to produce on the cost frontier. This, combined with the fact that scale efficiency was higher (on average) for each specialization group than technical and allocative efficiency, suggests that swine producers of all specializations would generally benefit by focusing more on producing on the frontier than on adjusting size.

Economic efficiency (EE) had a mean estimate of 0.53 across all firms and ranged (on average) from 0.42 (mixed producers) to 0.78 (weanling-to-feeder operators).[4] This range across operations is notably higher than the individual range of technical, allocative, or scale efficiency.

Overall efficiency (OE) averaged 0.48 for the entire data set, with 7% of the sample being estimated as overall efficient.[5] Average overall efficiency ranged across segmented groups from 0.38 (farrow-to-finish and mixed) to 0.76 (weanling-to-feeder). As noted in the economic efficiency discussion above, this range is significant. Figure 1 further demonstrates how overall efficiency varies across farm type. The graph demonstrates significant variation in the distributions across specialization. For example, it shows that only 15% of weanling-to-feeder producers are less than 50% efficient compared to 80% of farrow-to-finish operators.

In addition to estimating scale efficiency, returns to scale and optimal size were analyzed. Table 4 presents the results revealing that returns to scale vary considerably across firm specialization. Farrow-to-finish and farrow-to-feeder operations were estimated to be the two groups who could most benefit by increasing operation size as they were found to have the highest percentage of firms currently operating under increasing returns to scale. Conversely, 80% or more of the feeder-to-finish, farrow-to-weanling, and weanling-to-feeder operations were estimated to be working under decreasing returns to scale (on the increasing portion of the average cost curve). Overall, the finding of high scale efficiency (Table 3) and decreasing returns to scale for the majority of firms implies that the average cost curve is relatively flat (Rowland et al.). The optimal size of firms (as defined by minimizing average costs) in each specialization group is presented in table 5.

Tobit Model Results

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[4] Economic efficiency is defined as the product of technical and allocative efficiency.
[5] Overall efficiency is defined as the product of technical, allocative, and scale efficiency.

Likelihood ratio tests were used (Table 6) to identify whether the homoskedastic or heteroskedastic model specifications were more appropriate.[6] In all 35 models (7 data subsets and 5 different efficiency measures) the tests suggests that the heteroskedastic error specification is statistically more appropriate. Failing to acknowledge this and simply using the traditional homoskedastic Tobit model may lead to inconsistent parameter estimates. The estimation results for the heteroskedastic Tobit specifications are presented in table 7.

Analysis of the results reveals that input expenses, firm size, and demographic variables have mixed effects on each of the five efficiency measures for the different farm specializations. Furthermore, the heteroskedastic parameters vary considerably across models. With the exception of the models explaining scale efficiency, the estimated models generally reveal an inverse relationship between input expenses and firm efficiency. It is noteworthy that this does not hold in all cases and that the exceptions (e.g., positive impact of marketing expenses on allocative efficiency for farrow-to-finish and feeder-to-finish farms and the positive influence on overall efficiency of increased feed expenditures for farrow-to-weanling operators) should be noted and appreciated by producers, policy makers, and researchers.

Further examination of Table 7 reveals differences in how firm size impacts efficiency for each of the specializations. It is noteworthy that firm size had a positive and statistically significant impact (except for in the weanling-to-feeder group) in each of the overall efficiency models. This finding should be noted by individuals interested in farm size issues related to market power concerns as this analysis suggests that there are in fact efficiency gains to increasing firm size. It is interesting to note that farrow-to-finish operations are the only firms in which farm size has a significant impact on technical efficiency. This implies that the ability of

[6] See Table 6 for test statistic calculation formula.

most swine farms to produce on the production frontier is not actually impacted by operation size.

Examination of demographic effects demonstrates heterogeneous impacts on firms depending on their specialization. In general, age is estimated to have little impact on each efficiency measure. One notable exception to this is the fact that all five efficiency measures for farrow-to-weanling firms are significantly affected by age. Operator education and experience were found to have differing impacts on efficiency depending on firm specialization. Higher levels of education were found (ceteris paribus) to decrease overall efficiency of farrow-to-finish, farrow-to-weanling, and weanling-to-feeder farms. Conversely, more experience is estimated to increase overall efficiency for these same specializations. The number of years a producer anticipates to continue production appears to be positively related to overall efficiency of farrow-to-finish and weanling-to-feeder operations and negatively related for farrow-to-weanling producers. This finding may reflect a tendency of individuals who intend to remain in the industry for longer periods to adopt newer, more efficient practices than those who are likely to exit the industry and thus have a shorter time period to justify additional investments in new technologies.

Conclusions

Previous research on the efficiency of swine firms has been unable to study the effect of different technologies used in the rapidly changing swine industry. This work is particularly unique as it provides estimates of technical, allocative, scale, economic, and overall efficiency separately and jointly for “farrow-to-finish,” “farrow-to-feeder,” “feeder-to-finish,” “farrow-to-weanling,” “weanling-to-feeder,” and “mixed” operations. Heteroskedastic Tobit models are estimated to examine factors affecting efficiency measures and document heterogeneous impacts across organizational structures.

Efficiency measures differ appreciably across swine firm specialization. Significant differences in efficiency estimates are found to persist for firms in each of the analyzed specialization fields. Estimated Tobit models reveal that heterogeneity extends beyond specialization type and into the effect of various factors on efficiency estimates. In particular, input expenses, firm size, and demographic effects are found to have varying impacts on the evaluated efficiency measures. Furthermore, this analysis provides evidence that the optimal farm size varies significantly depending on the technology being employed.

The findings of this work have several important implications. This work shows that firms of differing specializations vary notably in their levels of efficiency and in the underlying factors influencing this efficiency. Furthermore, this research sheds light on the different impacts input expenses, operation size, demographic factors, and production technologies have on estimates of firm efficiency. Future work should take note of these differences across firm specialization by segmenting firms by the underlying technologies being used (when possible) and better noting the limitations of assuming firms to have the same technology when it is not feasible to segment groups by employed technologies.

There are numerous economic implications and contributions from this analysis. These include demonstrating the impact of incorrectly assuming technology homogeneity when heterogeneity persists, showing the different effects that demographic factors can have on firm efficiency, and providing additional evidence that increases in firm size are at least partially justified by gains in overall production efficiency. Policy makers and operators can better appreciate these facts and consequently make more informed and appropriate decisions for each specialization type. For instance, policy makers concerned with issues such as firm size can use this work as a guide in noting that firm size can be motivated by firms seeking to improve efficiency and that these factors differ substantially across firm specialization. Producers can utilize this work in several ways; such as guiding adjustment in their input mix to become more efficient or in considering growth such as moving from a farrow-to-feeder to a farrow-to-finish operation. Furthermore, researchers can take note of these issues and extend this work in many ways. For example, one could evaluate the extent and implications of producer heterogeneity in other industries, account for demographic factors such as producer expectations regarding the future, as well as provide a further examination of the swine industry using alternative data sets or modeling techniques.

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Table 1. Summary Statistics for Hog Producer Sample

	All Observations (n=1633)		Farrow-to-Finish (n=735)		Farrow-to-Feeder (n=130)		Feeder-to-Finish (n=492)	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Veterinary	22.55	30.52	24.86	32.05	38.50	47.04	11.18	15.78
Marketing	19.31	33.33	10.05	12.37	44.23	64.12	16.26	22.44
Feed	481.47	229.42	505.06	222.19	415.10	226.94	485.67	203.56
Labor	36.05	69.20	38.26	67.10	55.16	73.85	20.87	58.91
Capital	329.69	296.94	370.43	314.45	429.04	305.69	214.03	181.77
Miscellaneous	546.88	441.34	477.45	446.55	589.93	531.79	611.77	374.53
Profit	-655.52	798.61	-808.95	773.20	-794.23	870.74	-443.22	610.86
Animal Units	427.85	1742.61	379.20	2311.79	369.18	783.93	549.98	1321.21
Age	49.95	11.45	50.51	11.37	50.12	11.29	49.35	11.47
Education	2.59	0.99	2.57	1.00	2.69	1.06	2.58	0.91
Years Experience	20.57	13.13	24.70	12.68	16.43	10.64	17.32	12.37
Years Expected	3.97	1.82	3.75	1.86	3.96	1.92	4.16	1.72

	Farrow-to-Weanling (n=52)		Weanling-to-Feeder (n=53)		Mixed (n=171)	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Veterinary	33.34	36.61	35.38	22.04	25.95	29.49
Marketing	47.96	23.60	99.55	69.30	15.36	25.48
Feed	240.70	161.08	508.79	216.72	483.15	295.64
Labor	78.32	70.19	28.05	32.53	45.30	94.57
Capital	275.65	92.36	282.07	230.07	443.01	408.06
Miscellaneous	361.61	202.86	707.67	200.11	632.37	551.61
Profit	-451.95	368.65	436.63	517.92	-901.84	1035.90
Animal Units	399.88	430.86	493.23	448.94	318.45	618.01
Age	47.83	9.70	47.55	11.77	50.55	12.16
Education	2.52	1.04	2.57	0.93	2.68	1.10
Years Experience	9.65	8.36	8.75	9.38	22.30	13.53
Years Expected	4.71	1.27	5.17	1.22	3.82	1.87

* Table presents the mean and standard deviation (Std. Dev.) of the data utilized in this analysis. Units of measurement are as follows: *Veterinary*, *Marketing*, *Feed*, *Labor*, *Capital*, *Miscellaneous*, and *Profit* are expressed in dollars ($), *Age* and *Years Experience* is in terms of years, *Education* and *Years Expected* are categorical variables as described by McBride and Kay where higher values correspond with higher levels of education and expected production longevity.

Table 2. Regression Relationship Between Profit and Farm Characteristics

	Coefficient	Standard Error	p-value
Constant	5737.32	198.69	0.00
Farrow-to-Finish	-54.75	33.03	0.10
Farrow-to-Feeder	82.92	46.06	0.07
Feeder-to-Finish	213.95	36.84	0.00
Farrow-to-Weanling	-45.81	64.90	0.48
Weanling-to-Feeder	1336.09	65.95	0.00
Veterinary	0.89	2.64	0.74
Marketing	-13.43	7.63	0.08
Feed	-229.47	19.72	0.00
Labor	-9.08	1.75	0.00
Capital	-466.43	18.59	0.00
Miscellaneous	-455.12	18.99	0.00
Animal Units	77.61	9.76	0.00
Age	-3.86	0.97	0.00
Education	-1.38	10.18	0.89
Years Experience	2.09	0.88	0.02
Years Expected	8.92	5.81	0.13

* Model fit statistics include a R^2 of 0.77, log-likelihood of -12,011.35, and Durbin-Watson statistic of 1.95.

Table 3. Summary Statistics of Efficiency Measures

Firm Type	*TE*	*AE*	*SE*	*EE*	*OE*
All Observations	0.66	0.80	0.88	0.53	0.48
	(0.25)	(0.19)	(0.20)	(0.25)	(0.26)
Farrow-to-Finish	0.59	0.75	0.85	0.43	0.38
	(0.24)	(0.18)	(0.22)	(0.21)	(0.22)
Farrow-to-Feeder	0.83	0.79	0.88	0.66	0.59
	(0.20)	(0.18)	(0.21)	(0.24)	(0.27)
Feeder-to-Finish	0.72	0.90	0.92	0.64	0.60
	(0.21)	(0.12)	(0.17)	(0.21)	(0.23)
Farrow-to-Weanling	0.77	0.75	0.89	0.58	0.52
	(0.26)	(0.20)	(0.14)	(0.28)	(0.27)
Weanling-to-Feeder	0.88	0.88	0.97	0.78	0.76
	(0.15)	(0.15)	(0.06)	(0.20)	(0.21)
Mixed	0.60	0.69	0.89	0.42	0.38
	(0.28)	(0.25)	(0.23)	(0.28)	(0.29)

* Table presents the mean and standard deviation (in parentheses) of each efficiency estimate for each firm type.

Table 4. Returns to Scale Summary Statistics

Firm Type	*IRTS*	*CRTS*	*DRTS*
Farrow-to-Finish	303	2	398
	(0.41)	(0.00)	(0.54)
Farrow-to-Feeder	53	1	75
	(0.41)	(0.01)	(0.58)
Feeder-to-Finish	76	3	400
	(0.15)	(0.01)	(0.81)
Farrow-to-Weanling	4	1	47
	(0.08)	(0.02)	(0.90)
Weanling-to-Feeder	1	1	48
	(0.02)	(0.02)	(0.91)
Mixed	67	1	87
	(0.39)	(0.01)	(0.51)

* Table presents the number of firms (percentages are in parentheses) estimated to be operating with increasing (IRTS), constant (CRTS), and decreasing (DRTS) returns to scale.
** Some of the percentages don't add to 100% since firms with marginal costs estimated to be zero were omitted from returns to scale calculations.
*** Marginal costs estimates were obtained from estimated shadow values on the output constraint ($\mathbf{Y'Z} \geq y_i$) of the allocative efficiency linear programming problem (equation 2).

Table 5. Results of Optimal Firm Size Analysis

Firm Type	Animal Units$_L$[a]	Animal Units$_U$	Hogs$_L$[b]	Hogs$_U$
Farrow-to-Finish	47,604.77	96,478.70	198.35	401.99
Farrow-to-Feeder	141,008.69	254,121.65	2,820.17	5,082.43
Feeder-to-Finish	48,265.29	58,371.25	201.11	243.21
Farrow-to-Weanling	133,537.50	148,734.42	10,272.12	11,441.11
Weanling-to-Feeder	168,009.90	218,212.50	3,360.20	4,364.25
Mixed	52,498.78	54,325.87	N/A	N/A

* Table presents interval estimates of firm size for cost minimizers in each specialization. The ranges presented are the lower and upper bounds of 90% confidence intervals. Further, number of animals isn't provided for *Mixed* operations as they sell an array of animals.
[a] *Animal Units* is the number of pounds (liveweight) produced.
[b] *Hogs* is the number of animals produced assuming that finished hogs, feeder pigs, and weanlings are sold weighing 240, 50, and 13 pounds, respectively.

Table 6. Likelihood Ratio Test of Tobit Model Specifications*,**

	All Observations (n=1633)				
	TE	AE	SE	EE	OE
Test Statistic	69.83	62.13	331.12	100.69	137.72
	Farrow-to-Finish (n=735)				
	TE	AE	SE	EE	OE
Test Statistic	71.00	40.35	70.57	209.02	201.50
	Farrow-to-Feeder (n=130)				
	TE	AE	SE	EE	OE
Test Statistic	12.35	30.62	125.85	46.51	75.65
	Feeder-to-Finish (n=492)				
	TE	AE	SE	EE	OE
Test Statistic	26.98	36.52	266.78	21.07	29.84
	Farrow-to-Weanling (n=52)				
	TE	AE	SE	EE	OE
Test Statistic	149.63	140.11	141.43	186.12	153.45
	Weanling-to-Feeder (n=53)				
	TE	AE	SE	EE	OE
Test Statistic	112.09	106.71	178.51	61.95	69.13
	Mixed (n=171)				
	TE	AE	SE	EE	OE
Test Statistic	25.74	20.84	59.96	41.63	66.99

* $\text{Test Statistic} = 2*(LL^U - LL^R)$. LL^U denotes the log likelihood value from estimating the unrestricted (heteroskedastic) model. LL^R denotes the log likelihood value from estimating the restricted (homoskedastic) model.
** All 35 test statistics differ from zero at the 95% level or higher.

Table 7. Heteroskedastic Tobit Relationships Between Efficiency, Input Expenses, and Farm Characteristics

	All Observations (n=1633)					Farrow-to-Finish (n=735)				
	TE	AE	SE	EE	OE	TE	AE	SE	EE	OE
Intercept	2.09*	1.20*	0.32*	1.72*	1.03*	2.74*	1.49*	0.13	2.29*	1.24*
Veterinary	-0.01*[a]	0.00*[a]	0.00*[a]	-0.01*[a]	-0.01*[a]	-0.02*[a]	0.00[a]	0.00	0.00[a]	0.00[a]
Marketing	-0.02*	0.01*[a]	-0.01*[a]	0.00[a]	-0.01[a]	-0.07*[a]	0.02*[a]	-0.04*	-0.03*[a]	-0.03*[a]
Feed	-0.11*[a]	-0.03*[a]	0.01*[a]	-0.10*[a]	-0.07*[a]	-0.10*[a]	-0.06*[a]	-0.01[a]	-0.08*[a]	-0.04*[a]
Labor	-0.01*	0.00*[a]	0.00*[a]	-0.01*	-0.01*	-0.01*[a]	0.00	-0.01	-0.01*[a]	-0.01*[a]
Capital	-0.08*	-0.08*	0.02*[a]	-0.11*	-0.09*	-0.13*	-0.07*	0.03*[a]	-0.12*[a]	-0.09*[a]
Miscellaneous	-0.03*	0.05*[a]	0.03*[a]	0.02[a]	0.03*[a]	-0.10*	0.03*[a]	0.04*[a]	-0.07*	-0.02*
Animal Units	0.00	0.00[a]	0.07*[a]	0.00	0.06*[a]	-0.03*[a]	-0.02*[a]	0.12*[a]	-0.05*[a]	0.03*[a]
Age	0.00	0.00*	0.00[a]	0.00	0.00*	0.00	0.00*	0.00[a]	0.00	0.00[a]
Education	-0.01*	-0.02*	0.00[a]	-0.02*	-0.01*	0.00	-0.01*	0.00	-0.01[a]	-0.01*[a]
Experience	0.00*[a]	0.00*	0.00[a]	0.00*[a]	0.00*	0.00*[a]	0.00	0.01[a]	0.00*[a]	0.00*
Expected Yrs	0.02*[a]	0.00	0.00	0.01*	0.01*	0.02*	0.00	0.00	0.01*	0.01*

	Farrow-to-Feeder (n=130)					Feeder-to-Finish (n=492)				
	TE	AE	SE	EE	OE	TE	AE	SE	EE	OE
Intercept	2.59*	2.18*	0.78*	3.23*	1.46*	1.13*	1.03*	0.85*[a]	1.00*	0.86*
Veterinary	-0.06*	0.00[a]	0.00[a]	-0.02[a]	-0.03*[a]	0.00	0.00	-0.01*[a]	0.00	0.00
Marketing	-0.05*	-0.01[a]	0.00	0.03*[a]	0.04*[a]	-0.01[a]	0.05*	0.00[a]	0.01	0.00[a]
Feed	-0.14*	-0.04	0.01	-0.10*	-0.02	-0.04	-0.06*	0.01*	-0.05*	-0.02
Labor	-0.01*	0.00	0.00	-0.01*[a]	-0.02*[a]	0.00	0.00[a]	0.00	0.00	0.00
Capital	-0.05	-0.15*	0.00	-0.14*	-0.12*	-0.03	-0.02	0.00*[a]	-0.01	-0.03
Miscellaneous	-0.07	0.01[a]	0.00	-0.14*	-0.06*	0.02	0.03*[a]	0.00[a]	-0.01	-0.04*
Animal Units	0.01	-0.05*[a]	0.03*[a]	-0.06*[a]	0.05*[a]	0.00	0.03*	0.01*[a]	0.02*	0.07*
Age	0.00	0.00	0.00[a]	0.00*	0.00	0.00[a]	0.00	0.00[a]	0.00	0.00[a]
Education	0.03[a]	0.02	0.00	0.01	0.00	-0.01	-0.02*	0.00	-0.01	0.00
Experience	0.00	0.00	0.00	0.00[a]	0.00	0.00*	0.00	0.00	0.00*[a]	0.00[a]
Expected Yrs	0.02	-0.01	0.00	0.01[a]	0.01[a]	0.01	-0.01	0.00	0.01	0.00

* Denotes statistical significance of the coefficient estimate (B) at the 90% level or higher.

[a] Denotes statistical significance of the heterogeneous parameter (γ) at the 90% level or higher.

Table 7. Heteroskedastic Tobit Relationships Between Efficiency, Input Expenses, and Farm Characteristics (continued)

	Farrow-to-Weanling (n=52)					Weanling-to-Feeder (n=53)				
	TE	AE	SE	EE	OE	TE	AE	SE	EE	OE
Intercept	8.45*	1.98*	0.24*	6.22*	1.02*	3.50*	1.82*	-3.63	4.19*	4.01*
Veterinary	-0.11*[a]	-0.06*	-0.04*[a]	-0.14*	-0.16*[a]	-0.05*	0.01	0.02	-0.08*[a]	-0.13*[a]
Marketing	-0.10*	-0.09*[a]	-0.02*[a]	-0.09*	-0.12*[a]	-0.06*	0.06*	-0.19	-0.02[a]	0.00
Feed	-0.28*[a]	0.09*	0.05*	-0.02	0.19*	-0.34*[a]	-0.20*[a]	0.02	-0.39*[a]	-0.27*[a]
Labor	0.00[a]	-0.01*[a]	0.00[a]	0.00[a]	0.00[a]	0.00	0.00[a]	-0.08	0.00[a]	0.00[a]
Capital	-0.47*[a]	-0.12*	0.07*	-0.38*[a]	-0.06	-0.17*[a]	-0.13*	0.05	-0.13*[a]	-0.16*[a]
Miscellaneous	-0.30*[a]	-0.06*	-0.03*[a]	-0.23*	-0.05[a]	0.01[a]	0.04	0.59	-0.10	-0.17*
Animal Units	-0.11[a]	0.04	0.09*[a]	-0.17*	0.15*[a]	0.10[a]	0.04*	0.32	0.06[a]	0.06[a]
Age	-0.02*[a]	0.00*[a]	0.00*[a]	-0.01*	-0.01*[a]	0.00[a]	0.00*[a]	-0.01	0.01*[a]	0.01*[a]
Education	0.12*[a]	-0.12*	0.00[a]	0.06*[a]	-0.03[a]	-0.09*[a]	-0.04*[a]	-0.09*	-0.06*[a]	-0.05*
Experience	0.04*	0.01*[a]	0.00*[a]	0.02*[a]	0.01*[a]	0.01[a]	0.00[a]	0.00	0.00[a]	0.00*
Expected Yrs	-0.08*[a]	-0.08*[a]	-0.01*[a]	-0.09*[a]	-0.07*[a]	0.07*[a]	0.03*[a]	0.05*	0.08*[a]	0.09*[a]

	Mixed (n=117)				
	TE	AE	SE	EE	OE
Intercept	2.58*	1.48*	0.22	1.96*	0.84*
Veterinary	-0.01[a]	0.01*	-0.01*	0.00	0.00[a]
Marketing	-0.05*	-0.03*	-0.03*	-0.03*[a]	-0.04*[a]
Feed	-0.09*[a]	0.04	0.00	-0.02	-0.04
Labor	-0.01*	-0.02*	-0.02*	-0.01*	-0.02*[a]
Capital	-0.11*	-0.08*[a]	0.00	-0.10*[a]	-0.11*[a]
Miscellaneous	-0.11*	-0.03	0.05*	-0.08*[a]	0.02
Animal Units	0.00	-0.03	0.08*[a]	-0.04	0.03*[a]
Age	0.00	0.00*	0.00*	0.00	0.00
Education	-0.02	-0.01[a]	0.00	0.00	0.02*
Experience	0.00	0.00	0.00[a]	0.00	0.00
Expected Yrs	0.02	-0.01	0.00	0.01[a]	0.01[a]

* Denotes statistical significance of the coefficient estimate (B) at the 90% level or higher.

[a] Denotes statistical significance of the heterogeneous parameter (γ) at the 90% level or higher.

Figure 1. Cumulative Distribution of Overall Efficiency Estimates across Firm Type