MEASUREMENT AND EXPLANATION OF TECHNICAL EFFICIENCY IN MISSOURI HOG PRODUCTION

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Boubaker Ben-Belhassen, Post Doctoral Fellow
The Food and Agricultural Policy Research Institute (FAPRI)
University of Missouri-Columbia
101 S. Fifth Street, Columbia, MO 65201
Phone: (573) 882-4586
Email: BenbelhassenB@missouri.edu

Abner W. Womack, Professor and Co-Director
The Food and Agricultural Policy Research Institute (FAPRI)
University of Missouri-Columbia
101 S. Fifth Street, Columbia, MO 65201
Phone: (573) 882-3576
Email: WomackA@missouri.edu

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ABSTRACT

The U.S. live hog production has undergone a significant structural change characterized by a trend toward larger operations. Experts argue that there is a cost advantage for larger farms due to industrialization and increased management intensity. One important element in production, mainly for industries with rapid consolidation, is technical efficiency which affects the firm's competitive position directly. This study uses a stochastic production frontier function and farm-level data to measure and explain technical efficiency in Missouri hog production. The study estimates the mean technical efficiency for farms in the sample at about 82 percent, implying that a large proportion of production (18%) is lost due to farm-specific inefficiencies. Further, the results of the technical efficiency model proves the effects of technology and managerial skills on the level of productive efficiency. The study also finds economies of scale in hog production, thus explaining the consolidation in the industry.

Key words: technical efficiency, economies of scale, production frontier, econometric methods

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1. Introduction

The analysis of the hog industry has been a hot subject for applied economists and agribusiness analysts. Most of the research over the past few years has involved understanding the industry and the market as well as the competitive position of firms (Azzam, Lawrence et al.). The study of the swine industry is becoming even more important as the sector is coming under more competitive pressure from other livestock industries.

The U.S. hog industry has undergone significant structural and behavioral changes in the past two decades. The number of operations fell from 390,000 in 1985 to only 157,000 in 1996, a decline of 7.9 percent a year during that period. A remarkable structural change in the industry has been the trend toward fewer, larger, and more specialized swine operations. Between 1988 and 1997, the share of hog production by firms marketing 50,000 heads or more has increased from 7 percent to 37 percent, with 17 percentage point gain between 1994 and 1997 (Lawrence, Grimes, and Hayenga). Meanwhile, the share of firms marketing less than 1,000 heads has dropped from 32 percent in 1998 to 5 percent in 1997, with 12 percentage point decline between 1994 and 1997 (Table 1). Hog production in the United States is moving toward industrialization and increased management intensity (Rhodes). Hog industry experts argue that a significant cost advantage accrue to larger production operations that are capable of adopting and investing in new technologies and also in securing market access.

One plausible explanation for the consolidation or horizontal integration in the hog industry is increasing returns to scale. The concept of economies of scale is simply "the bigger, the better" in economic terms. Economies of scale is defined as the reduction in the average cost of a product over the long run due to a higher output level. Economies of scale can be either internal or external. The former arise from expansion in individual firms whereas the latter arise from expansion in the industry.

An important factor in hog production is efficiency as effective competition for consumers' food budgets requires the industry to operate efficiently. As the hog industry consolidates, productive efficiency becomes a vital issue in the race to establish a competitive position in both the domestic and international markets. Technical efficiency is a principal element in economic profitability as it measures the ability of the firm to produce maximal output from a given set of inputs. This will be reflected in the average cost of operation and, hence, will directly affect the competitive position of the firm.

The analysis of productive efficiency is important in economics and management science professions. Efficiency measures or indices are performance indicators and are of interest on their own. Furthermore, there is considerable interest in explaining the distribution of efficiency and in identifying its determinants. Results of such studies can assist public policy and managerial decision making (Caves and Barton). However, as in any empirical analysis, the results should be interpreted within their scope as they relate to specific case studies and data sets.

This paper is devoted to the analysis of technical efficiency of U.S. hog production and implications for management and competitive strategies. It uses the stochastic production frontier approach and farm level data from Missouri to measure hog productive efficiency and identify the (in)efficiency- maximizing (minimizing) techniques of hog farming. The second part of this study tests for the existence of economies of scale in the hog industry.

The remainder of this paper consists of four sections. The following section describes the analytical model and estimation techniques. The data is described in the third section. The next section presents the empirical results and discusses the findings. The last section gives a summary and concluding remarks for the study.

2. Model Development

This study adopts the stochastic production frontier approach developed by Aigner, Lovell and Schmidt, and utilizes the two-stage analytical procedure. In the first stage, a vector of individual technical efficiency indices for firms in the sample is generated, while in the second stage, an econometric analysis is done to explain intra-industry variations in inefficiencies. Several studies have used this approach in analyzing the determinants of technical (in)efficiency (e.g., Parikh and Shah; Kaparakis, Miller and Noulas; Martin and Page).

Following Kumbhakar and Hjalmarsson, firms are assumed to maximize output. This is consistent with the profit maximization hypothesis as the choice of inputs is made prior to output decision. Maximizing output is equivalent to maximizing profit with pre-determined (exogenous) input and output prices. Since this study treats inputs as exogenous to the model, maximizing output would satisfy the hypothesis of profit maximization.

The stochastic production frontier consists of a production function with a composite error term equal to the sum of two error components. The first error component, also called a statistical or white noise, accounts for random effects. The second component represents systematic effects that are not explained by the production function but attributed to technical inefficiency. A conventional production function, however, cannot capture this. In this study, the production frontier model is specified as follows:

$$Y_i = F(X_i; \beta)\exp(\upsilon_i - u_i) \qquad (1)$$

where Y_i is the quantity of output for firm i; X_i is an (n+1) row vector where the first element "1" represents the intercept and the remaining elements represent quantities of inputs employed to produce Y; β is an (n+1) column vector of technology parameters to be estimated; υ_i is a random error term assumed to be independently and identically distributed (iid) as $N(0, \sigma_\upsilon^2)$; and u_i is a one-sided error term ($u_i \geq 0$, $\forall$ i) representing technical inefficiency of farm i.

Note that in panel data, technical inefficiency varies over time too. However, it is usually assumed to be time-invariant mainly for short number of periods. But, for relatively long panel data, the assumption of constant technical inefficiency is not plausible (Cornwell, Schmidt and Sickles; Kumbhakar; Battesse and Coelli). Schmidt states, "unchanging inefficiency over time is not a particularly attractive assumption, but on the other hand it is a powerful one" (p. 313).

The stochastic production frontier, as defined in (1), is determined by the structure of the technology of production, or deterministic production frontier, and by external factors to the production process. The combination of both yields the stochastic production frontier. In the above representation, the deterministic production frontier is $F(X_i; \beta)$ and the stochastic frontier is $F(X_i; \beta)\exp(\upsilon_i)$.

Technical efficiency (*TE*) of farm *i* can be calculated with an output orientation method as the ratio of actual (observed) output relative to the potential (maximum feasible) output:

$$TE_i = \frac{Y_i}{F(X_i; \beta)\exp(\upsilon_i)} = \frac{E(Y_i | u_i, x_i)}{E(Y_i | u_i = 0, x_i)} \qquad (2)$$

This efficiency measure takes values between 0 and 1 with smaller ratios reflecting greater inefficiency. *TE* measures the percentage of actual output relative to the potential output that is produced from the same set of inputs by a fully efficient firm ($u_i = 0$), with a value of 1 indicating actual output equals frontier output. The frontier output is obtained by estimating the technology parameter vector using econometric methods or linear programming techniques.

In the estimation of the production function parameters, the Cobb-Douglas functional form is commonly utilized as it yields more efficient parameter estimates (Yao and Liu). In addition, output elasticities from the Cobb-Douglas form may be equivalent to those obtained from the translog specification at the sample mean (Greene). Following this tradition and for the purpose of this study, a Cobb-Douglas type production function is specified for Missouri hog production.

$$Y_i = B \prod_{j=1}^{n} x_{ij}^{\beta_j} e^{\varepsilon_i} \qquad (3)$$

where $\varepsilon_i = \upsilon_i - u_i$. The subscript i is used to index farms and subscript j is used to index inputs. The logarithmic form of (3) is:

$$\ln Y_i = \beta_0 + \beta_j \sum_{j=1}^{n} x_{ij} + \upsilon_i - u_i \qquad (4)$$

Since the frontier production function is specified in logarithmic form, technical efficiency index is defined following Battesse and Coelli:

$$TE_i = \exp(-u_i) \qquad (5)$$

However, to implement (5), technical inefficiency must be separated from the statistical noise in the composed error term ($\upsilon_i - u_i$). The measurement of u for individual observations in the sample is derived from the conditional distribution of u, given ε ($\varepsilon = \upsilon - u$):

$$E(u|\varepsilon) = \int_{-\infty}^{0} u\, f(u|\varepsilon)du \qquad (6)$$

where $f(\cdot)$ is the standard normal density function. Jandrow et al. showed that

$$E(u|\varepsilon) = \frac{\sigma_u \sigma_\upsilon}{\sigma}\left[\frac{f(\varepsilon\lambda/\sigma)}{1-F(\varepsilon\lambda/\sigma)} - \frac{\varepsilon\lambda}{\sigma}\right] \qquad (7)$$

where $F(\cdot)$ is the standard normal distribution function, $\sigma^2 = \sigma_u^{\ 2} + \sigma_\upsilon^{\ 2}$, and $\lambda = \sigma_u / \sigma_\upsilon$. Estimates for individual efficiency indices are calculated applying the following formula for values of $f(\cdot)$ and $F(\cdot)$ evaluated at $(\varepsilon\lambda/\sigma)$. Estimated values for ε, λ and σ are used to evaluate the density and distribution functions.

$$TE_i = \exp[E(u_i|\varepsilon_i)] \qquad (8)$$

In the second stage of the study, technical efficiency is used as a dependent variable. It is regressed against a set of explanatory variables representing the set of available technologies and the farmer's management skills. In econometric representation, the model is as follows:

$$u_i = \delta' \mathrm{Z} + \omega_i \qquad (9)$$

where Z is a vector of firm characteristic and technology variables, δ is a vector of parameters to be estimate, and ω_i is a random statistical noise iid as $N(0, \sigma_\omega^{\ 2})$ introduced to capture events beyond the control of farmers.

The second objective of the present study is to test for economies of scale in Missouri hog production. Note that the production function specified in (3) does not impose any restriction on the elasticity of scale of the industry. By definition, the elasticity of scale is estimated as the sum of partial elasticities of output with respect to each input (Hallam):

$$\kappa(x) = \sum_{j=1}^{n} \frac{\partial \ln y}{\partial \ln x_j} = \sum_{j=1}^{n} \beta_j \qquad (10)$$

The magnitude of κ indicates whether the industry exhibits economies of scale. The industry exhibits economies of scale if κ is larger than one, exhibits diseconomies of scale if κ is smaller than one, and constant returns to scale if κ equals one.

3. Data

The data was obtained from Missouri swine enterprise records and from the Extension Service of the Department of Agricultural Economics at the University of Missouri-Columbia. The data is for 1996 and includes 28 farms. The unit of observation is the room as different rooms from the same farm could bias the results if aggregated. The sample consists of a total of 92 rooms.

Output is measured by total weight of pig generated (or weight gain) and is calculated as the difference between total weight of animals on ending stocks and total weight of animals on beginning stocks. Four inputs are employed in the production function: (1) animals, measured by the total number of animals on beginning inventory; (2) labor, measured by the total number of man hours; (3) feed, measured by the total quantity of feed use (both grains and commercial); and (4) space, measured by area-per-animal as a proxy for capital. Another variable, the square of the number of animals, is added into the equation.

4. Empirical Results

The empirical results of the stochastic production frontier are presented in Table 1. The model was estimated using Maximum Likelihood (ML) technique since the technical inefficiency term is not symmetrically distributed, but truncated at zero ($\tau_i \geq 0$, $\forall$ i). The estimated frontier model is:

$$\ln(output_i) = \beta_0 + \beta_1 \ln(animals_i) + \beta_2 \ln(feed_i) + \beta_3 \ln(labor_i) + \beta_4 \ln(space_i) + \beta_5 \ln(animals_i)^2 + u_i - v_i \tag{11}$$

As reported in Table 1, all the variables included in the empirical model, except one, are significant at the 5 percent level. The remaining variable, square of the number of animals, is however significant at the 10 percent level. The number of animals, labor, total feed use, and the size of the room all have positive regression parameter estimates, suggesting that an increase in these variables would result in higher weight gains. However, the square of the variable number of animals per room is negative, implying the law of diminishing returns in hog production. Higher number of animals will increase weight gain up to some point, then it will have a negative effect beyond that. This may be explained by that a (very) large number of animals in the room will result in over-crowding and stepping problems and may also result in management and feeding difficulties. This also imply some optimal number of animals per room.

The estimation results also indicate the relative importance of factor inputs in hog production. The number of animals appears to be the most important factor in hog production with an elasticity of 0.42[1], followed by feed use with an elasticity of 0.37, labor with an elasticity of 0.29, and room-per-animal with an elasticity of 0.18. The sum of partial output elasticities is larger than 1, thus suggesting the existence of economies of scale in hog production in Missouri. This also explains, at least in part, the consolidation in the industry and the appearance of larger scale farms at the expense of smaller farms. Larger growers are able to achieve higher production

[1]The elasticity with respect to the number of animals is calculated at the mean values due to the second order term of this variable.

levels (thus decreasing their cost of production) and to enhance their competitive position in the market place. As hog farms become larger in size but fewer in number, this may lead to a market characterized by some kind of oligopoly power in the future.

The results also estimate the mean technical efficiency at 0.824[2], implying that production, on average, is about 18 percent below the frontier (or maximum feasible output). This also means that a significant proportion of production is lost due to farm-specific technical inefficiency. At the same time, the distribution of individual technical efficiency indices indicate a large variation in the level of efficiency in the sample with individual index estimates ranging from a minimum of 0.722 to a maximum of 0.956. The wide variation in the level of technical efficiency suggest the importance of farm specific characteristics such as the nature of technology and the grower's management skills in attaining higher levels of productive efficiency. The frequency distribution of technical efficiency is presented in Table 2.

The calculation of technical efficiency for individual observations allows identification of factors influencing the level of this index. Therefore, such analyses help growers, industry experts, and policy-makers in terms of improving efficiency and achieving higher productivity levels. Based on literature and theory, variations in technical efficiency is due to farm-specific characteristics and farmer's technical knowledge. Accordingly, two sets of variables representing individual characteristics and the grower's technical knowledge are considered in this study to examine the variations in individual technical efficiencies. The first set includes the building type, the floor type, and pig flow type. The second set consists of two variables - the number of

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[2]The mean technical efficiency for the sample is calculated as $TE = 2\,[1 - F(\sigma)]\exp(\sigma^2/2)$. For details see Battesse and Coelli (1988).

years of experience in hog farming and the level of education of the farmer, to account for the effects of managerial skills.

There are three types of buildings: confinement naturally ventilated; confinement power ventilated; and outside housing. Two dummy variable (DBL1 and DBL2) are used to assess the effect of building type on efficiency. Four dummy variables (DFR1, DFR2, DFR3, DFR4) are specified to measure the effect of floor type on efficiency as there are five different floor types: dirt; dirt and concrete; solid concrete; partial slats with concrete; and full slats with concrete. There are two types for animal flow: all-in/all-out and continuous flow. A dummy variable (DFL) is used to estimate the effect of pig flow on efficiency. For farmer's knowledge, two quantitative variables, the number of years in hog farming (EXP) and the number of years in school (SCL), are defined to test whether differences in managerial skills would have any effect on technical efficiency. The estimation results are presented in Table 3.

All the variables included in the efficiency model are found to be statistically significant at the 5 percent level. This supports our hypotheses that the nature of the technology employed by the farmer and the farmer's management skills are important determinant of the level of technical efficiency, thus affecting the competitive position of the farm. The results suggest that both inside building types outperform outside housing in terms of technical efficiency. The parameter estimates also indicate that inside housing with power ventilation increases technical efficiency. The regression coefficients on the floor type variables are all positive, implying that the dirt floor type would reduce (increase) technical (in)efficiency. Also, based on the parameter estimates, we can conclude that full slatted concrete floor would result in greater technical efficiency relative to other floor types. Regarding animal movement between housing, the results suggest that all-in/all

-out is a better practice by increasing the level of technical efficiency. Based on these findings, we may recommend the combination of inside housing with power ventilation, concrete floor with full slats, and the all-in/all-out animal flow to achieve higher efficiency levels.

The estimation results also indicate that the farmer's education and knowledge are both statistically significant, suggesting the importance of management skills in improving the level of technical efficiency. The latter finding is specifically important for policy makers in that a more efficient extension service and also more frequent training programs for farmers would improve the level of technical efficiency in hog production.

5. Summary and Conclusions

This study contributes to the empirics of technical efficiency and the analysis of hog production in the United States. The U.S. hog industry has witnessed several structural changes in recent years. The most significant change has been the trend towards larger and more specialized hog operations. Statistics indicate that the share of firms marketing 50,000 heads or more has soared from 7 percent in 1988 to 37 percent in 1997, while that of firms marketing less than 1,000 heads has shrunk from 32 percent to only 5 percent during the same period. However, as the industry consolidates, technical efficiency becomes a more important factor in the race in order for firms to maintain their competitive position in the market and stay in business.

This study applies a production frontier model to a cross-sectional data set of Missouri hog farms to analyze sources of technical (in)efficiency in the sector. The study also tests for the existence of scale economies in the hog industry. The Maximum Likelihood (ML) estimation of the production frontier suggests that animals are the most important factor of production with an elasticity of 0.42, followed by feed with an elasticity of 0.37, labor with an elasticity of 0.29 and space with an elasticity of 0.18. The empirical results indicate that hog farming is characterized by economies of scale, which has certainly contributed to the consolidation of the industry. The mean technical efficiency for the sample is estimated at 0.824, suggesting that production is on average 18 percent short of the frontier. This also indicates possibilities for improvement and for the sector to be more efficient. In the second part of the study, individual measures of efficiency were regressed on a set of explanatory variables in order to identify factors that could contribute to the improvement of technical efficiency.

The estimation results of the technical efficiency model prove the importance of technology and management skills in determining efficiency levels. Seven qualitative variables are used to explain efficiency differentials due to building type, animal flow type, and waste management technique. Two quantitative variables - years in school and years of experience - are used to capture the effects of the farmer's knowledge on technical efficiency. The findings suggest that confinement with power ventilation, all-in/all out pig flow, and concrete floor with full slats will increase technical efficiency relative respectively to other types of buildings, animal flows, and waste management. The results also indicate that the farmer's education level and experience have significant positive effects on efficiency. Therefore, training programs and a more efficient extension service should be considered by policy makers as a way to improve efficiency levels.

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Table 1. Share of Hog Production by Firm Size in the United States, 1988-1997 (in percent)

Size (Head)	1988	1991	1994	1997
< 1,000	32	23	17	5
1,000 - 2,000	19	20	17	12
2,000 - 3,000	11	13	12	10
3,000 - 5,000	10	12	12	10
5,000 - 10,000	9	10	12	10
10,000 - 50,000	12	13	13	16
> 50,000	7	9	17	37

Source: Lawrence, Grimes, and Hayenga (1998)

Table 2. Maximum Likelihood Estimation Results for the Production Frontier Model

Variable	Parameter	Parameter Estimate	t-Statistic[a]
Constant	β_0	8.46	4.27
Animals	β_1	0.68	5.23
Labor	β_2	0.37	3.02
Feed	β_3	0.29	3.44
Space	β_4	0.18	2.36
Animal Square	β_5	-0.12	-1.72

[a]figures reported are asymptotic t-statistics

Table 3. Frequency Distribution of Individual Technical Efficiency Measures

Interval	Number of Observations	Percentage
0.71 - 0.75	7	7.6
0.75 - 0.80	17	18.5
0.80 - 0.85	34	36.9
0.85 - 0.90	21	22.8
0.90 - 0.95	11	12.0
0.95 -1.00	2	2.2
Total	92	100

Table 4. Estimation Results for the Technical Efficiency Model

Variable	Parameter Estimate	t-Statistic
Constant	0.322	5.27
DBL1 (confinement, power ventilation)	0.118	2.62
DBL2 (confinement, natural ventilation)	0.084	2.28
DFR1 (concrete, full slats)	0.106	3.16
DFR2 (concrete, partial slats)	0.072	2.33
DFR3 (solid concrete)	0.052	1.57
DFR4 (dirt and concrete)	0.014	0.96
DFL (all-in/all-out)	0.112	3.34
SCL (years in school)	0.092	2.03
EXP (years of experience)	0.101	2.77
R^2	0.468	