A Nonparametric Analysis of Efficiency for a Beefpacking Firm: Implications of Federal Food Safety Regulations

by

Allen M. Featherstone

and

Nicole L. Klein[*]

Selected Paper Submitted to the

1997 Western Agricultural Economics Association Meetings

March 1997

[*]Allen Featherstone is a Professor in the Department of Agricultural Economics, Kansas State University, and Nicole Klein is an Assistant Professor in the Department of Economics, South Dakota State University.

Corresponding Author:
Dr. Nicole L. Klein
Department of Economics
Box 504A Scobey Hall
South Dakota State University
Brookings, SD 57007

Telephone: 605-688-4847
FAX: 605-688-6386
E-Mail: kleinn@ur.sdstate.edu

A Nonparametric Analysis of Efficiency for a Beefpacking Firm: Implications of Federal Food Safety Regulations

Abstract

Nonparametric analysis is used to measure efficiency and examine the impact of the zero tolerance directive on the efficiency of a major U.S. beefpacker. Regulatory compliance costs have caused the plants to not be able to use the best available technology in the production process.

A Nonparametric Analysis of Efficiency for a Beefpacking Firm: Implications of Federal Food Safety Regulations

With foodborne illness outbreaks such as the *E. coli* 0157:H7 outbreak in the Pacific Northwest in 1993, there has been an increasing concern with food safety. In light of this concern and in an effort to become more "science-based," the Food Safety and Inspection Service (FSIS) -- the branch of the US Department of Agriculture (USDA) responsible for meat inspection -- has implemented major changes in the federal system of meat inspection. As a result of the foodborne illness outbreak in the Pacific Northwest, FSIS issued a zero tolerance directive causing FSIS meat inspectors to stop slaughter lines and trim all identifiable feces, ingesta or milk on beef carcasses. Later that year, inspectors were instructed to slow the line speeds if there was not an adequate job of eliminating all contamination. This directive has increased the downtime of the slaughter and fabrication lines and has resulted in an increased loss of meat product from trimming. Other changes that have since occurred in the federal meat inspection program include ground beef testing which began in 1994, and the "Pathogen Reduction, Hazard Analysis Critical Control Point (HACCP) Systems" rule, which was introduced in July 1996 and is the most significant change in the federal meat inspection program since its inception in 1906.

With these changes in the federal meat inspection program, it is important to quantify the impact these changes have had on the meat processing sector. A significant amount of economic research has been done on the consumer side, i.e. consumers' willingness to pay for safer food (Hayes et al.; Buzby and Seeks; Eom; Huang; Choi and Jensen; and Zellner and Degner), and the direct societal cost of foodborne illnesses (Marks and Roberts; Roberts, 1991; and Roberts, 1989), but little economic research has examined the impact of increased food safety rules on the meat processors. The purpose of this study is to examine the effect of the zero tolerance directive on the efficiency and the cost structure of a major U.S. beef packer using nonparametric production analysis.

Nonparametric Production Efficiency

The nonparametric approach proposed by Färe, Grosskopf, and Lovell is used to analyze efficiency in the beef products industry and the impact of food safety issues on beefpackers. The use of nonparametric analysis does not impose a priori parametric restrictions on the underlying technology (Chavas and Aliber). The approach suggested by Färe, Grosskopf and Lovell allows one to estimate overall, allocative, pure technical, and scale efficiency. In this paper, a technique for measuring economies of scale is developed.

Technical efficiency (λ_i) relates to whether a firm uses the best available technology in its production process. It is a measure of the distance a firm is off the production function under variable returns to scale. In general, $0 \leq \lambda_i \leq 1$, and if $\lambda_i = 1$, then the firm is producing on the production frontier and is said to be technically efficient. Technical efficiency is determined by solving the following linear program (LP) problem for each observation:

$$
\begin{array}{ll}
 & \text{Min } \lambda_i \\
s.t. & x_{11} z_1 + x_{12} z_2 + \ldots + x_{1k} z_k \leq x_{1i} \\
 & x_{21} z_1 + x_{22} z_2 + \ldots + x_{2k} z_k \leq x_{2i} \\
 & \quad . \quad . \quad . \quad . \quad . \\
 & \quad . \quad . \quad . \quad . \quad . \\
 & x_{n1} z_1 + x_{n2} z_2 + \ldots + x_{nk} z_k \leq x_{ni} \\
 & y_1 z_1 + y_2 z_2 + \ldots + y_k z_k - y_i \geq 0 \\
 & z_1 + z_2 + \ldots + z_k = 1.
\end{array}
\tag{1}
$$

where z_k measures the intensity of use of the kth observation's technology, x_{nk} represents use of the n^{th} input in the k^{th} observation, y_i represents output produced, and subscript i represents the firm of interest. The last equation restricts the intensity vector to sum to one, and restricts the technology to be variable returns to scale. The intensity variables represent the efficient technology set by choosing the best technologies from the observations in the sample which produce at least that output for the ith observation.

Allocative efficiency (γ_i) examines a firm's ability to choose its inputs in a cost minimizing way. In general, $0 \leq \gamma_i \leq 1$, and if $\gamma_i = 1$, then the firm is allocatively efficient. Allocative efficiency is determined by dividing the cost under variable returns to scale technology (T_v) by the actual cost adjusted for technical efficiency (λ_i):

$$\gamma_i = \frac{C_i(w, y, T_v)}{w'_i \ \lambda_i \ x_i}, \tag{2}$$

where the denominator is the actual cost the ith observation incurred to produce y_i multiplied by technical efficiency. The cost under variable returns to scale is found by solving the following LP program for each observation:

$$\begin{aligned} C_i(w, y, T_v) &= \text{Min } w'_i x_i \\ s.t. \quad x_{11} z_1 + x_{12} z_2 + \ldots + x_1 k z_k &\leq x_{1i} \\ x_{21} z_1 + x_{22} z_2 + \ldots + x_2 k z_k &\leq x_{2i} \\ \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot& \\ \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot& \\ x_n 1 z_1 + x_n 2 z_2 + \ldots + x_{nk} z_k &\leq x_{ni} \\ y_1 z_1 + y_2 z_2 + \ldots + y_k z_k - y_i &\geq 0 \\ z_1 + z_2 + \ldots + z_k &= 1. \end{aligned} \tag{3}$$

The third measure of efficiency, scale efficiency, refers to whether a firm is at the most efficient size. Scale efficiency (θ_i) is defined as:

$$\theta_i = \frac{C_i(w, y, T_c)}{C_i(w, y, T_v)} \tag{4}$$

where the numerator represent costs under constant returns to scale, and is found by solving the following LP program for each observation:

$$
\begin{aligned}
C_i(w,\, y,\; T_c) \;=\; & \text{Min}\;\; w'_i\, x_i \\
s.t.\;\; & x_{11} z_1 + x_{12} z_2 + \ldots + x_1 k\, z_k \;\le\; x_{1i} \\
& x_{21} z_1 + x_{22} z_2 + \ldots + x_2 k\, z_k \;\le\; x_{2i} \\
& \quad\quad .\;\;.\;\;.\;\;.\;\;. \\
& \quad\quad .\;\;.\;\;.\;\;.\;\;. \\
& x_n 1 z_1 + x_n 2 z_2 + \ldots + x_{nk} z_k \;\le\; x_{ni} \\
& y_1 z_1 + y_2 z_2 + \ldots + y_k z_k - y_i \;\ge\; 0.
\end{aligned}
$$

(5)

The minimum cost from this LP is divided by the minimum cost from model 3 on an observation by observation basis to calculate scale efficiency.

Overall efficiency (ρ_i) represents the minimum cost of producing the level of output for the i^{th} observation, given input prices and a constant returns to scale technology. It is the product of technical, allocative, and scale efficiency:

$$
\rho_i \;=\; \frac{C_i(w,\, y,\; T_c)}{w'_i\, x_i} \;=\; \lambda_i \,*\, \gamma_i \,*\, \theta_i .
$$

(6)

If $\rho_i = 1$, then the firm is overall efficient which implies it is technically, allocatively and scale efficient.

Economies of scale (EOS) is defined as the relative increase in output resulting from a proportional increase in all inputs, and is found by dividing average cost by marginal cost:

$$
EOS_i(w,\, y,\; T_v) \;=\; \frac{C_i(w,\, y,\; T_v) / y_i}{MC_i(w,\, y,\; T_v)} ,
$$

(7)

where $MC_i(w,y,T_v)$ is equal to the shadow price on the output constraint in Model 3 and average cost is determined by the cost of Model 3 divided by the units of output. If EOS equals one, the firm's underlying production function exhibits constant returns to scale (CRTS), indicating that a doubling of all inputs will exactly double output. If EOS is less than one, the technology exhibits decreasing returns to scale (a doubling of all inputs will lead to a less than doubling of output). Likewise, if EOS is greater than one, then the technology exhibits increasing returns to scale (a doubling of all inputs will lead to a greater than doubling of output).

Data and Methods

The nonparametric methodology is applied to 5 plants of a major U.S. beefpacking firm[1] for 14 semi-annual time periods (November 1988 through May 1995), for a total of 70 observations in a pooled data set. Data from the firm's financial records, along with federal data, are used in the analysis. To maintain the firm's confidentiality, the means of the raw data are not reported. Five inputs are used: capital, labor, cattle, energy, and a composite category of all "other" inputs. Output is measured as total dressed weight at slaughter. Each plant's expenditure for each input is divided by input price to obtain a measure of quantity of inputs used. Total expenditures on capital are measured by summing expenditures on depreciation, rent, and total repairs and maintenance. Total expenditures on labor include all wages, salaries, and benefits for the following operations: slaughter, fabrication, maintenance, and general plant operations. These operations comprise over 90% of the firm's labor expenses. Total expenditures on cattle are represented by the total cost of live carcasses. Expenditures on energy consist of all expenditures on utilities. Total expenditures on "other" inputs are calculated by subtracting expenditures on capital, labor and energy from total processing expenses.

The implicit cost of capital consists of two components: the real rate of interest and capital depreciation. The real rate of interest was calculated by subtracting the (semi-annual) rate of inflation (measured by semi-annual movements in the consumer price index) from semi-annualized Baa bond rates (Goodwin and Brester). Consumer price indices were taken from *CPI Detailed*

---

[1] As a condition of obtaining the data, the name of the beefpacking firm cannot be disclosed.

Report (U.S. Dept. of Labor) and the bond rates were six month averages (December through May, and June through November) of monthly Baa bond rates reported in the *Survey of Current Business* (U.S. Dept. of Commerce), and *Moody's Bond Survey* for the months of March 1994 through May 1995. The depreciation component of the user cost of capital was calculated by dividing plant depreciation by net property values. Net property values are fixed assets less plant depreciation.

Average hourly earnings for production workers in meat packing plants (SIC 2011), obtained from *Employment and Earnings* (U.S. Dept. of Labor), are used as a proxy for the price of labor. The average price paid for cattle on a per head basis by this firm is calculated by dividing the total cost of live cattle by total number of head slaughtered. The producer price index for fuels, related products, and power, taken from *Producer Price Indexes* (U.S. Dept. of Labor), was used for the price of energy. The Index of Food Marketing Costs, taken from *Monthly Food Marketing Cost Index Data* (U.S. Dept. of Agriculture, Economic Research Service), is used to determine a price index for "other" inputs using a Tornquist index (Moschini).

Three linear programs are solved for each of the 5 plants for each time period (Models 1, 3, and 5). Based on these results, overall, allocative, technical and scale efficiency for each of the firms for each of the 14 time periods are calculated. An economies of scale for each plant is estimated using equation 7. Tobit models are used to examine the relationship between the efficiency measures and plant characteristics:

$$\begin{aligned} IE_i &= \sum_{i=1}^{n} \beta_i X_i + e_i \quad \text{if} \sum_{i=1}^{n} \beta_i X_i + e_i > 0, \\ &= 0 \qquad\qquad \text{otherwise,} \end{aligned} \qquad \textbf{(8)}$$

where IE_i is the measure of inefficiency for each observation, X_i is a vector of explanatory variables for the i^{th} observation, and e_i is the normally distributed error term. The efficiency measures are converted to inefficiency measures by subtracting them from one. Binary variables for each plant and the amount of downtime caused by compliance with the zero tolerance regulation in both the slaughter and fabrication operations are used as the explanatory variables. The total minutes of downtime along with the minutes of downtime caused by regulation compliance in both the slaughter and fabrication operation have been kept by the firm since the introduction of the zero tolerance directive (May 1993). The average amount of weekly downtime incurred because of compliance with the zero tolerance regulation (minutes that the line is stopped for trimming) is multiplied by the number of weeks in each semi-annual period to obtain a regulatory compliance cost variable. The regulatory compliance cost variables are set to zero for periods prior to 1993, under the assumption that there was no downtime caused by compliance with the zero tolerance directive prior to its inception.

To explore which parts of plant operations are most likely associated with efficiencies, econometric models are estimated to examine the relative importance of each input on a per pound of output basis in explaining efficiency, as well as to examine the impacts of plant characteristics and input factors on economies of scale. Once it is determined what plant characteristics and inputs are most highly associated with efficiency, the firm will better be able to focus their efforts on areas that could increase efficiency.

Efficiency Results

Overall efficiency ranged from 0.87 to 1.00 with an average of 0.94 (Table 1) indicating that, in general, the plants are very efficient. On average, if the plants were producing on the cost frontier, the same level of output could have been produced with 6% less cost. The plants operated at between 90% and 100% efficiency over 85% of the time.

In general, this beefpacker has made very efficient use of the technology available to it -- over 40% of the time the plants were perfectly technically efficient (Table 1). Plants number two and five were purely technically efficient in each of the 14 time periods. Over 90% of the time, the plants were operating at a level of at least 95% technical efficiency. Technical efficiency measures ranged from 0.92 to 1.00, with an average of 0.98. On average, the firm could increase output by 2% if each plant was operating on the production function in each time period.

Allocative efficiency varied from 0.91 to 1.00, with an average of 0.97 (Table 1). While only three observations were perfectly allocative efficient, over 75% of the observations were at least 95% allocative efficient.

Scale efficiency measures were also high, ranging from 0.94 and 1.00 and averaging 0.98. All but one of the observations were at least 95% scale efficient. Graphically, scale inefficiency represents the distance between a horizontal line at the minimum average cost and the cost frontier given in Figure 1. The line in Figure 1 represents the minimum cost frontier while the diamonds represent the average cost per unit of output for each observation. Percent above the minimum observation are put on the axes of the graph rather than numbers in order to protect the confidentiality of the beefpacking firm. The difference between the average cost per observation and the cost frontier represents technical and allocative inefficiency. The minimum cost frontier is determined by dividing $C_i(w,y,T_v)$ in Equation 3 by y_i to get the minimum average cost per head.

Economies of scale measures ranged from 0.96 to 1.32, with an average of 1.16 (Table 1). In general, the plants of this firm operate in areas of increasing returns to scale.

Regression results that identify the factors associated with inefficiencies and scale measures are reported in Table 2. Models that explain technical, allocative, scale, and overall inefficiencies are estimated using Tobit while the economies of scale model (EOS) is estimated using OLS. Downtime in the slaughter operation caused by the zero tolerance regulation was positively related to technical inefficiency. Greater amounts of downtime caused by the zero tolerance regulation lead the plants to be less technically efficient, indicating that there is an inverse relation between regulatory compliance costs from the zero tolerance regulation and plants' abilities to use the best available technology in the production process.

Increased regulatory compliance costs in the slaughter operation were inversely related to all of the other inefficiency measures -- allocative, scale and overall inefficiency. Thus, the zero tolerance requirement is associated with less technical efficiency in the packing industry but more overall efficiency.

Plants one and three were significantly less technically efficient than plant five. Plants number three and four were less allocative efficient than plant five was, and were also less efficient overall than plant five. Plant one was more scale efficient than plant five, indicating that it was operating at a more efficient size.

Increased regulatory compliance costs in the slaughter operation was negatively associated with economies of scale. This indicates that the greater the amount of downtime caused by compliance with the zero tolerance regulation lead to decreased measure of economies of scale for the plant for that time period. Plant number one had a significantly lower economies of scale measure, while plant three had a significantly higher economies of scale measure than plant five.

Conclusions

The beefpacking industry has been operating under changing regulations from the federal government in response to concerns from society for a safer meat supply and the need for a more science-based method of meat inspection. As a direct response to the 1993 *E. coli* 0157:H7 outbreak in the Pacific Northwest, FSIS issued a zero tolerance directive which caused costly downtime for beefpacking plants.

This study used nonparametric analysis to examine the efficiency of a specific major U.S. beefpacker and the impact of the zero tolerance directive on its efficiency. Technical, allocative, scale and overall efficiency as well as economies of scale were examined for five of the plants in the firm for each of 14 semi-annual time periods (November 1988 through May 1995). The firm was found to be relatively technically, allocatively and scale efficient. Technical efficiency and scale efficiency averaged 98%, while allocative efficiency averaged 97%. Over 40% of the time, the plants in this firm were perfectly technically efficient. In general, most of the plants in this firm operated in areas of increasing economies of scale.

Downtime caused by compliance with the zero tolerance directive in both the slaughter and fabrication operations, as well as qualitative variables for each plant, were regressed on each of the inefficiency measures. Downtime in the slaughter operation was negatively related to technical inefficiency, while it was positively related to all other inefficiency measures, including overall inefficiency. This suggests that the zero tolerance directive has caused the plants to not be able to get as much output per unit of input. Downtime in the slaughter operation also had a negative impact on economies of scale measures for the firm, again indicating that the directive is associated with the plants operating at a more efficient scale.

Table 1. Efficiency Measures for Plants in a Specific Beef Packing Firm

Variable	Technical	Allocative	Scale	Overall	EOS
Summary Statistics					
Mean	0.98	0.97	0.98	0.94	1.16
Standard Deviation	0.02	0.02	0.01	0.03	0.14
Minimum	0.92	0.91	0.94	0.87	0.96
Maximum	1.00	1.00	1.00	1.00	1.32
Distribution of Observations					
Less than 0.899	---	---	---	10	---
0.900 to 0.924	2	4	---	14	---
0.925 to 0.949	4	12	1	24	---
0.950 to 0.974	11	20	19	14	22
0.975 to 0.999	24	30	47	6	---
1.000	28	3	2	1	---
1.001 to 1.250	---	---	---	---	17
1.251 and up	---	---	---	---	30
Average by Plant					
Plant #1	0.98	0.98	0.99	0.95	0.96
Plant #2	1.00	0.97	0.98	0.88	1.24
Plant #3	0.97	0.96	0.98	0.91	1.25
Plant #4	0.99	0.95	0.98	0.92	1.18
Plant #5	1.00	0.97	0.98	0.95	1.19

Table 2. Relation Between Plant Characteristics and Inefficiency Measures as well as Economies of Scale[a]

Independent Variable	Technical	Allocative	Scale	Overall	EOS
Intercept	-0.6854*	1.9285***	2.0511***	2.6259***	1.2252***
	(0.3703)	(0.3388)	(0.3436)	(0.3716)	(0.0229)
Downtime-Slaughter	0.0045***	-0.0049***	-0.0059***	-0.0030**	-0.0005***
	(0.0014)	(0.0013)	(0.0014)	(0.0013)	(0.0001)
Downtime-Fabrication	-0.0138	-0.0036	0.0083	-0.0090	0.0007
	(0.0085)	(0.0078)	(0.0077)	(0.0077)	(0.0006)
D1	1.6635***	-0.4562	-1.2689***	0.0845	-0.2588***
	(0.4571)	(0.3853)	(0.3974)	(0.3824)	(0.0297)
D2	0.2443	-0.3100	-0.1433	-0.2485	0.0372
	(0.4750)	(0.3995)	(0.3967)	(0.3962)	(0.0306)
D3	1.6277***	1.0944***	0.3203	2.0196***	0.0813***
	(0.4777)	(0.4178)	(0.4061)	(0.4404)	(0.0314)
D4	0.7516	1.2311***	-0.0978	1.2170***	-0.0047
	(0.4711)	(0.4167)	(0.4005)	(0.4135)	(0.311)

[a] Standard errors are in parenthesis. Significance levels are as follows: * = 10%, ** = 5%, *** = 1%.

References

Buzby, J.C. and J.R. Seeks. "Consumers Want Reduced Exposure to Pesticides on Food." *FoodReview.* 17(May-August 1994):19-22.

Chavas, J.P. and M. Aliber. "An Analysis of Economic Efficiency in Agriculture: A Nonparametric Approach." *Journal of Agricultural and Resource Economics.* 18(July 1993):1-16.

Choi, E.K. and H.H. Jensen. "Modeling the Demand for Food Safety and the Implications for Regulation." Working paper, Iowa State University Center for Agricultural and Rural Development. 1990.

Eom, Young Sook. "Pesticide Residue Risk and Food Safety Valuation: A Random Utility Approach." *American Journal of Agricultural Economics.* 76(November 1994):760-771.

Färe, R., S. Grosskopf, and C.A.K. Lovell. *The Measurement of Efficiency of Production.* Boston: Kluwer-Nijhoff, 1985.

Goodwin, B.K., and G.W. Brester. "Structural Change in Factor Demand Relationships in the U.S. Food and Kindred Products Industry." *American Journal of Agricultural Economics.* 77(February 1995):69-79.

Hayes, D.J., J.R. Shogren, S.Y. Shin, and J.B. Kliebenstein. "Valuing Food Safety in Experimental Auction Markets." *American Journal of Agricultural Economics.* 77(February 1995):40-53.

Huang, C.L. "A Simultaneous System Approach for Estimation of Consumer Risk Perceptions, Attitudes, and Willingness-To-Pay for Residue-Free Produce." Selected paper presented at the American Agricultural Economics Association 1993 annual meeting, Orlando, FL.

Marks, S. and T. Roberts. "*E. coli* 0157:H7 Ranks as the Fourth Most Costly Foodborne Disease." *FoodReview.* 16(September-December 1993):51-58.

Moody's Bond Survey. Moody's Investors Service. New York. various issues.

Moschini, G. "Units of Measurement and the Stone Index in Demand System Estimation." *American Journal of Agricultural Economics.* 77(February 1995):63-68.

Roberts, T. "Human Illness Costs of Foodborne Bacteria." *American Journal of Agricultural Economics.* 71(1989):468-74.

_____. "A Survey of Estimate Risks of Human Illness and Costs of Microbial Foodborne Disease." *Journal of Agribusiness.* 9(1991):5-23.

U.S. Department of Agriculture, Economic Research Service. *Monthly Food Marketing Cost Index Data*. Washington, DC.

U.S. Department of Commerce, Economic and Statistics Administration, Bureau of Economic Analysis. *Survey of Current Business.* Washington DC: various issues.

U.S. Department of Labor, Bureau of Labor and Statistics. *CPI Detailed Report.* Washington DC: various issues.

U.S. Department of Labor, Bureau of Labor and Statistics. *Employment and Earnings.* Washington DC: various issues.

U.S. Department of Labor, Bureau of Labor and Statistics. *Producer Price Indexes*. Washington DC: various issues.

Zellner, J.A. and R.L. Degner. "Consumer Willingness to Pay for Food Safety." Paper presented at 1989 Annual meeting of Southern Agricultural Economics Association, Nashville, TN.