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The Impact of HACCP on Factor Demand and Output Supply Elasticities of Red Meat

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Abstract

This study uses firm-level data during the hazard analysis critical control point (HACCP) implementation period (1997 - 2000) to analyze the impact of HACCP on input demand and output supply elasticities of firms in the red meat industry and derive implications for efficiency and moral hazard issues associated with the implementation of HACCP systems. The results show that HACCP causes factor demand for labor, material, and capital to be less inelastic while the elasticity of output supply did not change significantly. The interdependent relationships among HACCP and input prices and output result in efficiency gains.

Key words: HACCP, factor demand, elasticities of substitution, output supply elasticities, translog cost function, efficiency, red meat

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Introduction

In an effort to reduce food-borne microbial pathogens, the National Advisory Committee on Microbiological Criteria for Foods (NACMCF) first developed Hazard Analysis of Critical Control Points (HACCP) principles for food production in November, 1989. In July, 1996 the USDA published the final Pathogen reduction/HACCP (PR/HACCP) rule for meat and poultry. As of January 25, 2000 all Federal and State inspected plants in the United States operate under mandatory PR/HACCP regulation. The USDA recently noted that Salmonella occurrence has reduced since the insertion of PR/HACCP. However, issues related to firm-level costs and benefits of PR/HACCP, its implications on factor demand and output supply continue to pose even greater challenges because the market for food safety has limited differentiation.¹

Firm-level analysis of PR/HACCP has largely focused on cost. The USDA estimated that firms in the red meat industry will incur most of the PR/HACCP costs (about \$734.67 million) over the PR/HACCP implementation phase. It is hypothesized that this cost will adversely affect the demand for inputs (labor, materials, carcass, etc.) and the supply of output (causing firms to produce only products they can afford to implement a PR/HACCP system). However, the quality management literature, on which the foundations of PR/HACCP are based, suggests that PR/HACCP provide cost saving benefits at the firm level. Cost impacts of PR/HACCP have important implications on how firms effectively implement PR/HACCP. Even though salmonella incidence has declined, microbial outbreaks continue to occur in firms with approved PR/HACCP systems. For example, in 2002 alone, the Centers for Disease Control (CDC) reported two outbreaks of *e. coli* in hamburger, resulting in 28 reported cases nationwide and 2 cases in New York; and 1 outbreak of *listeria* in turkey deli meat resulting in 43 reported

cases in 7 states. Microbial outbreaks with PR/HACCP systems may persist if firms perceive PR/HACCP as costly, increasing their expenditure on input factors. Firm-level uncertainty about the costs and benefits of PR/HACCP systems may contribute to moral hazard problems, ineffective implementation of PR/HACCP, and continuous outbreaks and food recalls.

A major role of food safety economists is to provide demand analysis estimation to evaluate the impact of food safety systems on input demand and output supply, to assist industry representatives and policy makers to better perceive the costs and benefits of such systems. This study uses a translog cost function to analyze the impact of PR/HACCP on input demand and output supply elasticities of firms in the red meat industry and derive implications for efficiency and moral hazard issues associated with the implementation of HACCP systems. The translog cost function is well-known for its flexible functional form in terms of local-order approximation to any arbitrary functional form. Using Shepard's lemma, the cost share equations can be derived by differentiating the translog cost function with respect to input factors. The cost shares and estimated parameters are then used to calculate conditional factor demand elasticities and output supply elasticities during the PR/HACCP implementation period. Elasticities of size estimates are used to derive implications for efficiency and revealed moral hazard behavior for firm implementing PR/HACCP systems.

Review of Relevant Literature

Economists' value added to food safety has been significant in estimating costs and benefits to society as a whole (using cost of illness methods), evaluating cost-effective regulatory options, estimating firm-level costs of food safety systems like PR/HACCP, and evaluating trade issues (Caswell). There have been very few studies on demand analysis estimation for safer products

due to limited product differentiation in the market for food safety. There is a need for better and more economic impact analysis of food safety systems especially in understanding private and public incentives to reduce food safety risks. In this section, we examine the current state of PR/HACCP in the red meat industry and review prior economic impact studies relating to costs and benefits. This section lays the foundation for understanding potential market implications of PR/HACCP.

Current State of HACCP and Firm-level Microbial Testing Requirements

Although all federal and state inspected firms are currently implementing mandatory HACCP, there are still several challenges at the firm level. In the final proposed PR/HACCP reduction rule of 1996 the firms had to determine their critical control points (CCPs) and the agency monitors these CCPs. This was primarily because the nature of continuous improvement constrained the agency to establish set standards for CCPs. Using risk assessment the agency has designed two CCPs for slaughter, three CCPs for packaging and fresh processing, and one CCP for cooked or smoked processing. These processes constitute the current regulatory HACCP. Most cooked or smoked processing firms operate what they term scientific HACCP with five CCPs. This information is useful in determining firm-level HACCP liability and efficiency gains. *Salmonella* testing for slaughtering and fresh processing is done by the agency. Small firms with less than 2.5 million dollars in sales, collect 12 samples over a one-time period of 12 weeks during the year. These samples are mailed to the agency to conduct the test at \$10 to \$12 per sample and about \$12 for shipping and handling. Larger slaughtering and processing firms collect one sample for everyone hundred thousand heads killed and processed. The cost for shipping and handling per sample are the same. Firms are also required to collect

13 samples for *e. coli* testing. Testing for *e. coli* costs the firms \$400 to \$425 for regulatory HACCP.

The major regulatory costs burden is on cooked and smoked processors. They collect 40 samples year round for *e. coli* and *Salmonella*. They send 20 of these samples to the agency and conduct their own bacteria testing for the remaining samples. They are also required to collect 17 samples for *Listeria* per week. These firms spend on average \$3,000 on testing for every half million pounds of products they produce. Approximately 10 hours of labor at \$12 to \$17 per hour is spent on every half million pounds of products. The major drawback for these firms is the wait time required to get the agency's approval to deliver the products.

Prior PR/HACCP Cost and Benefit Studies

Some theoretical and empirical studies have been conducted on HACCP costs and benefits (MacDonald and Crutchfield; Ravenswaay and Hoehn; and Roberts et al.) but the focus has been on society as a whole. According to Crutchfield et al., the USDA's Economic Research Service (ERS) estimated the net present value of the proposed HACCP systems (over a 20-year period) to be between \$6.4 billion and \$23.9 billion to society as a whole while the costs of implementing HACCP is estimated to be only \$1.9 billion.

The limitation on analyzing HACCP cost and benefits from a societal stand point are twofold. First, these studies do not explicitly address issues of equitable distribution of food safety costs and risks. Second, benefits and costs have been estimated separately and comprehensive industry impact analysis on how PR/HACCP affect input and output elasticities are seldom discussed, even though the industry is mandated to implement PR/HACCP. Separate estimation of HACCP costs and benefits may not capture the cross effects of PR/HACCP on other

inputs, as management science studies suggest.

Although HACCP is viewed at the firm level as a liability, HACCP as a management tool is internally driven by the fact that the cost of poor quality products exceeds the cost of developing processes which produce safer and high quality products.² Some potential benefits at the firm-level suggested by Ravenswaay and Hoehn are the ability of PR/HACCP systems to avert product avoidance and brand switching. While there may be potential savings from implementing PR/HACCP, firm-level impact studies prior to January 2000, for the U.S. may only contain anticipated HACCP data.³ This study builds on prior PR/HACCP cost estimation by Nganje and Mazzocco, but derives factor demand and output supply elasticities of substitution of PR/HACCP and other inputs and output. The study also analyzes efficiency and moral hazard implications associated with food safety systems.

Model Specification

A translog specification is used to represent the cost function of firms in the red meat industry. The translog cost function provides a flexible functional form with well known properties and methods to derive factor demand and supply elasticities. The generalized translog cost function with m -outputs and n -inputs specified by Ray is presented in equation 1. It incorporates a time component that is used to evaluate changes in technology or input mix, as in the case of PR/HACCP. Another advantage of the translog (dual) functional form is that it is a quadratic approximation of the “true” cost function (Ray). So, other than being a flexible functional form, a global minimum cost can be estimated. The translog is flexible because specific features of the technology (like homotheticity) may be tested by examining the estimated model parameters.

Another functional form used in the literature is the random coefficient regression model of Hildreth and Houck. Hornbaker, Dixon, and Sonka adopted this model to estimate production activity costs. The model basically reduced to a heteroscedastic model, which was estimated using a generalized least squares (GLS) method. The shortcomings of this model are that it had no time series component and that it had a strong assumption about the convergence of the sigma matrix. Knowledge of the sigma matrix is usually limited. The dual system approach used in this study overcomes this problem and increases efficiency in estimation.

$$(1) \quad \ln C = \ln K + \sum_{i=1}^m a_i \ln q_i + 1/2 \sum_{i=1}^m \sum_{j=1}^m d_{ij} \ln q_i \ln q_j + \sum_{r=1}^n b_r \ln w_r + 1/2 \sum_{r=1}^n \sum_{s=1}^n f_{rs} \ln w_r \ln w_s + \sum_{i=1}^m \sum_{r=1}^n g_{ir} \ln q_i \ln w_r + hT.$$

The variables in this equation are: “ C ” is cost or the dependent variable, “ q_i ” is output of product i , “ w_r ” is the price of input r , “ h ” is the error term, “ m ” is the number of outputs produced, “ n ” is the number of inputs used, “ T ” is the annual or technological index of time, and “ K ” is the constant term. This model is a generalization of the Cobb-Douglas (C-D) model. The model differs from the Cobb-Douglas model in that it relaxes the C-D assumption of a unitary elasticity of substitution. We can obtain the C-D model from this model by restricting $d_{ij} = f_{rs} = g_{ir} = 0$ (Greene). The translog cost function is positive, symmetric, and linearly homogenous in input prices. The implications of these restrictions are discussed.

Homogeneity Restriction. A valid cost function must be homogenous of degree one in input prices. To ensure linear homogeneity conditions, the restrictions below are imposed during estimation of the cost function.

$$\sum_{r=1}^n b_r = 1, \quad \sum_{s=1}^n f_{sr} = 0, \quad \sum_{i=1}^m g_{ir} = 0 \quad (r=1,2,\dots,n)$$

Slusky's Symmetry Restrictions and Concavity. The fact that the translog cost function is a second-order approximation (Chambers) implies Slusky's symmetry of the form $d_{ij} = d_{ji}$ and $f_{rs} = f_{sr}$ for all i, j, r , and s . Concavity of the cost function is met by imposing the restriction that the parameter matrix $[f_{rs}]$ or the Hessian matrix of the cost function is negative semi-definite.

Homotheticity Restriction. If the technology is homothetic, the dual cost function is multiplicatively separable in output quantities and input prices (Ray). The cost function $C = C(q, w)$ is of the form $h(q) * t(w)$, where " q " and " w " are vectors of output quantities and input prices. In equation 1, this requires that $g_{ir} = 0$ (for all i and r) so that the quadratic interaction term between output levels and input prices should disappear (Antle; Ray). The specified function will be tested for homotheticity to improve efficiency in estimation, that is, if the function is homothetic $g_{ir} = 0$.

Estimation Problems. One problem with multi-output, multi-input cost functions is the large number of variables to be estimated. For an m -output, n -input model with matrices (d_{ij}) and (f_{rs}) symmetrical, one needs to estimate $\frac{1}{2}(m + n)(3 + m + n)$ parameters (Ray). This does not include the intercept and the rate of Hicks-neutral technical progress. For example, in the case of two outputs and five inputs, we must estimate thirty-seven parameters. In general, it is difficult to obtain a sample large enough to estimate the full cost function. Thus, estimating the full cost function, even with the restriction of homogeneity in input prices may result in a classic specification problem with negative degrees of freedom.

Estimating a full dual system of cost and cost shares leads to much higher efficiency (Garcia and Sonka; Ray) due to the decreased number of parameters estimated. This procedure resolves the problem of lost specification error due to the decreased degrees of freedom required for the cost share system. Using equation 1 and Shephard's lemma, the input share equations are derived.

$$(2) \quad s_r = b_r + f_{r1} \ln w_{r,t} + \dots + f_{rn} \ln w_{n,t} + g_{i1} \ln q_i + \dots + g_{im} \ln q_m$$

where $r=1, \dots, n$, $s_r = w_r x_r / C$, and x_r is the quantity of the r th input. The sum of these shares must be one. For this to be true for all prices and outputs, it requires:

$$\sum_{r=1}^n b_r = 1, \quad \sum_{s=1}^n f_{sr} = 0, \quad \sum_{i=1}^m g_{ir} = 0$$

(for $r = 1, \dots, n$). This condition is the same for linear homogeneity of the cost function in input prices.⁴ With the assumption of marginal cost pricing for the outputs, we obtain the revenue share equations by differentiating the cost function with respect to output.

$$(3) \quad Y_i = \alpha_i + d_{i1} \ln q_{i,t} + \dots + d_{im} \ln q_{m,t} + g_{r1} \ln w_r + \dots + g_{rn} \ln w_n$$

where $i=1, \dots, m$, $Y_i = p_i q_i / C$, and q_i is the quantity of the i th output.

Derivation of Factor Demand and Output Supply Elasticities

Following Uzawa, the Allen partial elasticities of substitutions (AES) between inputs r and s can be calculated as

$$(4) \quad \sigma_{rs} = \frac{f_{rs} + s_r s_s}{s_r s_s} \quad \forall \quad r \neq s, \text{ and}$$

$$(5) \quad \sigma_{rr} = \frac{f_{rr} + s_r^2 + s_s}{s_r^2} \quad \forall \quad r = s.$$

Let ε_{rs} be the price elasticity of input demand for input r with respect to price of input s ,

$$(6) \quad \varepsilon_{rs} = \frac{\partial \ln x_r}{\partial \ln w_i} = \frac{\partial \ln x_r}{\partial \ln w_s} \cdot \frac{w_s}{w_r}.$$

Allen showed that the price elasticity of input demand for production can be directly calculated from the AES as: $\varepsilon_{rs} = \sigma_{rs} * S_r$. Once the estimate of σ_{rs} has been obtained, the matrix of price elasticity of input factor demand can be calculated. The price elasticity of output supply is obtained when derivatives are taken with respect to output. A necessary and sufficient condition for the translog cost function to be concave requires that all eigenvalues of the matrix σ_{rs} be non-positive. That is, the matrix of AES is negative semi-definite.

Blackorby and Russell argued that the AES provides no information about the curvature of the isoquant and the relative cost shares, and can not be interpreted as the marginal rate of substitution, making AES completely uninformative. Morishima proposed an alternative measure of substitution, known as the Morishima elasticity of substitution (MES). The MES is defined as a logarithmic derivative of a quantity ratio with respect to a marginal rate of substitution or a ratio of input prices. It measures the curvature of the isoquant and the effects of changes in price ratios on relative cost shares. According to Blackorby and Russell, the MES can be written as

$$(7) \quad \omega_{rs} = \varepsilon_{rs} - \varepsilon_{rr} = \frac{f_{rs} + s_r s_s}{s_s} - \frac{f_{rr} + s_r^2 - s_r}{s_r} \quad \forall \quad r \neq s,$$

The MES can also provide complete information about relative factor cost shares in response to a change in factor prices (Huang). This measure can be written as

$$(8) \quad \lambda_{rs} = 1 - \omega_{rs}.$$

The relative cost share is decreasing (increasing) if the MES is greater (less) than one. This measure and calculations of economies of size were used to derive implications for efficiency and moral hazard associated with food safety systems like PR/HACCP.

Derivation of Economies of Size and Biased Technical Change Estimates

Returns to scale refers to the change in output as inputs are multiplied by a scalar. The relative change in output can be represented by an elasticity of scale. Increasing returns to scale exist when the elasticity of scale is greater than one. Elasticity of size is the ratio of average cost to marginal cost. Chambers points out that these measures are very different. If one evaluates economies of size and finds them to be less than one, it implies that the firm involved can decrease average costs by decreasing production or implementing a different technology. This will be an interesting implication for small and large firms in the meat industry under PR/HACCP. The product specific economies of scale (PSES) gives information about changes in cost as individual firm activities expand (McClelland, Wetzstein, and Musser). Thus equations 9 and 10 assume that marginal cost is equal to marginal revenue and equal to Price.

$$(9) \quad PSES = \sum \partial \ln C / \partial \ln Q = (Q/C) \sum \partial C / \partial Q = PQ/C$$

$$\text{where } Q = \sum_{i=1}^m q_i.$$

Variables “C” and “q” are as specified previously. Economies of size from equation 9 is given by;

$$(10) \quad ES = (\sum \partial \ln C / \partial \ln Q)^{-1}.$$

Technical Change. Several methods have been used in the literature to estimate biased technical change. Antle presents a summary of these methods and their drawbacks. The Hicks-neutral technical change, based on the marginal rate of technical substitution, identifies biases between input pairs. However, it does not give a global picture of technical change. Therefore, the multi-factor measure proposed by Binswanger and adopted by Antle was used in this study. In this study, and as confirmed by Antle, no distinction is made between this method and the cost-share approach. Given the cost function $C(q,w)$, the i th cost elasticity for the i th input in the estimated cost function is given by,

$$(11) \quad \eta_i = \partial C / \partial X_i,$$

$$\eta = \sum_i^n \eta_i$$

Where the cost share of input i is given by $C_i = \eta_i / \eta$.

Biased Technical change β_i can now be defined using C_i as in equation (12) below. Technical change is biased against the use of input i if β_i is less than zero and it is biased toward input i if β_i is greater than zero. In the HACCP context, bias against input i will indicate the possibility of cost cutting incentives or high leverage which the firm can enjoy by reducing cost with this input factor over time. Biased technical change is given by:

$$(12) \quad \beta_i = \partial \ln C_i / \partial \ln T$$

Variable C_i is given as in equation 1 and the specification of T is made prior to and after HACCP implementation. Technical change is neutral with respect to input i when $\beta_i = 0$.

Data and Estimation Procedure

To estimate a cost structure for firms prior to and after PR/HACCP, equation 1 was reduced to a translog cost function with one aggregated output, one PR/HACCP input variable aggregating all HACCP expenses, and three other inputs (carcass purchase, labor, and material) of the firm. The empirical cost function model is presented in equation 13. This cost function model uses weighted input prices (w_1 - w_4) for all variables and output quantity (y). The price of labor (w_3) is in dollars per hour including benefits (e.g., health insurance and retirement benefits). The variable w_2 is the price per pound of fresh carcass or live animals purchased. The price for PR/HACCP (w_1) is the price per pound or total PR/HACCP expenses divided by output. The variable w_4 is the weighted price for material expenses and utilities. The output y is the aggregated quantity of fresh cuts, ham, sausages, and others. In equation 13, t = time index used for technical change, y = output quantity, and all other variables are as specified previously. To increase efficiency in the estimation, a system of four equations was estimated, including three cost shares. Using weighted prices and aggregated output did not significantly effect the results since the system of equations uses cost shares or expenditure shares in conjunction with prices.

$$\begin{aligned}
(13) \quad \ln C &= \alpha_0 + \gamma_y \ln y_t + \alpha_1 \ln w_{1,t} + \alpha_2 \ln w_{2,t} + \alpha_3 \ln w_{3,t} + \alpha_4 \ln w_{4,t} + \\
& \quad 1/2(\gamma_{11} \ln w_{1,t} \ln w_{1,t} + \gamma_{12} \ln w_{1,t} \ln w_{2,t} + \gamma_{13} \ln w_{1,t} \ln w_{3,t} + \\
& \quad \gamma_{14} \ln w_{1,t} \ln w_{4,t} + \gamma_{22} \ln w_{2,t} \ln w_{2,t} + \gamma_{23} \ln w_{2,t} \ln w_{3,t} + \\
& \quad \gamma_{24} \ln w_{2,t} \ln w_{4,t} + \gamma_{33} \ln w_{3,t} \ln w_{3,t} + \gamma_{34} \ln w_{3,t} \ln w_{4,t} + \\
& \quad \gamma_{44} \ln w_{4,t} \ln w_{4,t}) + \gamma_{y1} \ln Y_t \ln w_{1,t} + \gamma_{y2} \ln Y_t \ln w_{2,t} + \\
& \quad \gamma_{y3} \ln Y_t \ln w_{3,t} + \gamma_{y4} \ln Y_t \ln w_{4,t} + \gamma_{yy} (\ln y_t)^2 + \eta_t \\
s_1 &= \alpha_1 + \gamma_{11} \ln w_{1,t} + \gamma_{12} \ln w_{2,t} + \gamma_{13} \ln w_{3,t} + \gamma_{14} \ln w_{4,t} + \gamma_{y1} \ln Y_t \\
s_2 &= \alpha_2 + \gamma_{22} \ln w_{2,t} + \gamma_{12} \ln w_{1,t} + \gamma_{23} \ln w_{3,t} + \gamma_{24} \ln w_{4,t} + \gamma_{y2} \ln Y_t \\
s_3 &= \alpha_3 + \gamma_{33} \ln w_{3,t} + \gamma_{23} \ln w_{2,t} + \gamma_{13} \ln w_{1,t} + \gamma_{34} \ln w_{4,t} + \gamma_{y3} \ln Y_t
\end{aligned}$$

This system of four equations is estimated using Shazam. Three cost share equations were used because cost shares sum to one and using all cost shares will cause the matrix not to be full rank. Elasticities, economies of size estimates, and biased technical change are derived from equation 13 as discussed previously. Elasticity of size estimates require coefficients of the quadratic interaction term of output and input prices ($\ln y \ln w_i$), output ($\ln y$), and the quadratic interaction term of output ($\ln y \ln y$). This is especially important because the test for non-homotheticity (Ho: Coefficient of $\ln y \ln w_i = 0 \forall_i$) requires output in the cost function specification. Our estimation incorporates these variables.

To estimate the empirical models for this study, data on input and output prices and quantities for all production activities are needed. Secondary data on HACCP were not available for the detailed analysis required for this study. Therefore, a field survey had to be conducted to collect specific HACCP data. Data were collected for all HACCP input variables and other firm data relating to labor, material, and carcass and live animal purchases. A mail survey approach was chosen due to cost considerations. The population is U.S. red meat processors and packers.

It is important to note that firm-level PR/HACCP data for the meat industry is not publicly available. Consequently, a survey was designed to obtain firm-level data on prices and expenses before and after PR/HACCP implementation. The target population for this study consisted of meat processing and packaging firms in the United States. A list of firms in the Meat Industry was provided to us by the American Association of Meat Processors (AAMP). This list consisted of the names of firms across the United States and the name of the contact person(s), address, and telephone number for each firm. Cost considerations precluded surveying all firms. Based on the approach of Rea and Parker, a planned sample size of 990 would provide for a minimum standard error of the sample distribution at a 95% confidence level and would provide a confidence interval (sample error) of 3% for the entire population.

The survey questionnaire was developed following a comprehensive review of firm-level PR/HACCP implementation. The questionnaire was screened and pre-tested three times to adjust the clarity, accuracy, and natural flow of the questions. The final questionnaire had three sections and 31 questions (to collect data on all input and output volume and prices, including detailed PR/HACCP expenses). After double mailing, follow-up post cards, and telephone reminders, only 98 firms responded. Of the 98 respondents, only 63 provided detailed PR/HACCP data through the entire period. This response rate maintained the level of confidence at 95%, but the sampling error increased to 9.9%. The majority of the firms (46), were small firms with less than \$2.5 million annual sales volume. This is consistent with the fact that the majority of the firms in the industry are smaller firms. The distribution of production cost, described later in the descriptive statistics section, was also consistent with industry data. The firms that provided data

were monitored in 1997 and then, in order to collect ex-post firm-level PR/HACCP data, again in 2000 after PR/HACCP implementation.

When providing data, firms were advised to use tax and sales information to respond to survey questions. Data on the input and output prices and quantities for all firms prior to and after PR/HACCP implementation were used in the analysis. Total output for each product category (fresh cuts, smoked cuts, smoked and fresh sausages, and byproducts) is reported in pounds. The unit of measurements for output price is dollars per pound. Weighted output price is used for the analysis. Weighted output price is computed by summing the product of the price and the quantity for each product category and dividing this sum by the total output from all product categories. The weighted output price multiplied by total output yields the same gross revenue as compared to multiplying each product category by its price before summing the revenue from each category.

The carcass price used for the analysis is the dollar per pound of fabricated carcass and not the live weight. The price of labor used is the hourly wage rate plus benefits. The unit material price is computed by summing the product of total units and the price per unit and then dividing by the total number of units of all materials purchased. Depreciated items and their values are included as material expenses. The unit PR/HACCP expense is computed by dividing total output by the sum of all PR/HACCP expenses (labor and training expenses, testing costs, and operating and depreciated material expenses).

The descriptive statistics of the data reveal that all PR/HACCP expenses contribute about 0.4% of total firm expenses while material, labor, and carcass purchase contributed 13.5%, 20.3%, and 65.8%, respectively. PR/HACCP expenses translate to about 2.5 cents

per pound of product on average. This average is relatively higher than the USDA estimates of 0.24 cents per pound reported by MacDonald et al., probably because the USDA estimates were for larger size firms. Antle pointed out that the USDA estimates ignored the cost of designing and operating the testing system (to verify that the system is achieving its objectives).

In 1997, data was collected from 68 firms. Twenty-one of these firms did not have PR/HACCP systems and 34 of the firms were small (less than \$2.5 million in sales). In 2000, all firms had PR/HACCP systems, so we could update the data set. Four of the small firms had shut down; one due to owner death and three because of economic hardship, and one of the big firms was bought out. Out of the 63 currently in the data set, 46 are small firms. These data was used for the analysis in this study.

Results

This section contains estimates of the translog cost functions for all 63 firms and for a subset of 46 small firms. Estimation results of the nonlinear system of cost function and cost share equations are presented in Table 1. The variable HP is HACCP cost per pound, CP is price per pound of carcass purchased, LP is wage per hour of labor (this includes hourly wage, health insurance, and retirement benefits), MP is price per unit of operating material, and Y is output quantity. Because of the large number of parameters, only parameters of the full cost function are reported. Parameters of the equations were restricted to be equal to parameters of the full cost function equation and are not reported.

In general, the two cost functions were non-homothetic.⁵ The models have very good fit, with high R^2 . The standard errors of estimation were low and the models have a good number of

significant variables. The constant terms were positive and significant at the 1% level for all models. This implies that firms may lose some fixed cost expenses if zero output is produced. In general, the cost function results indicate that per unit production costs decrease as output increases. This is an indication that firms with larger output in the industry may have some economies of scale or that small firms are underutilizing current capacity or that they are inefficient. PR/HACCP expenses, labor use, and carcass purchase (in their linear or quadratic forms) were significant at the 1% and 5% level. As expected, PR/HACCP expenses significantly affect the cost of small firms. However, this variable was not significant when data from all firms were estimated jointly, possibly because of the effects of larger firms with some form of quality management systems, prior to implementing PR/HACCP. From the cost structure results it is difficult to conclude how PR/HACCP expenses may impact small firms because the quadratic interaction term of PR/HACCP expenses and other variables were significant and negative. Estimates of elasticities of substitution and efficiency of size analysis are needed to adequately arrive at such inferences.

Factor Demand and Out Supply Elasticities

Using the parameter estimates of the translog cost function, the Allen partial elasticities of substitution (AES) were calculated according to equations 4 and 5 at the sample mean of the cost shares for firms in the red meat industry and reported in left hand panel in Table 2. The positive signs indicate substitution relationships between any pair of inputs, except for $HP*LP$ (PR/HACC and labor use) and $MP*LP$ (material and labor). A significant substitution relationship was found between $HP*CP$ (PR/HACCP and carcass) and $HP*OP$ (PR/HACCP and output). There were other significant substitution relationship between $CP*LP$ (Carcass and labor) and $CP*MP$

(carcass and material use) however, the substitution relationship between *HP* (PR/HACCP) and other inputs are interesting in providing a comprehensive economic impact analysis of food safety risk management systems, and will be investigated further using economies of size efficiency analysis and biased technical change. The price elasticities of factor demand and output supply, shown in the right panel of Table 2, are inelastic. However, the price elasticity of PR/HACCP and output supply are positive.

In contrast to the AES, which is partial adjustment to the price of one factor, the Morishma elasticity of substitution (MES) reflects the adjustment of relative factors in response to a change of relative factor prices. The MES for all factor input and output are shown in the lower left panel of Table 2. The MES for “all firms” and “small firms” are positive and greater than one, for all PR/HACCP quadratic factors, confirming a strong substitution relationship between PR/HACCP and other input factors and output. It is also interesting to note that the price impact, on the lower right hand panel, for “PR/HACCP and carcass” and “PR/HACCP and material” are negative, confirming that as firms spend more money on PR/HACCP they reduce expenses on these inputs. The effect of PR/HACCP on output, although positive, was not significantly greater than 1, indicating it cannot be confirmed whether safety system like PR/HACCP will boost consumers’ confidence and increase sales. On the other hand, the negative elasticities indicate reduction in cost shares for the respective factors.

Although the AES and the MES suggest little difference in the substitution results Huang suggested that this inconsistency may be caused by the different definitions of these two elasticities. On a positive note, the price impacts from both the AES and the MES yielded similar conclusions.

Economies of Size and Bias Technical Change

The economies of size efficiency estimates from equation 10 are presented in Table 3. All firms, including the subset of smaller firms enjoy economies of size efficiency gains with PR/HACCP systems. Economies of size estimates after implementing PR/HACCP were -1.2281 and -2.3405 for all firms and small firms respectively. A t-test indicated that these economies of size estimates were significant at the 5% level. This implies that firms do enjoy lower marginal cost after PR/HACCP implementation either from decreasing output or producing a higher level of output at the same cost. A critical factor in efficiency gains analysis is to identify sources of efficiency gains. Biased technical and earlier tests on homotheticity and used to address this question.

HACCP as a Technical Change which Biases Input Mix. Biased technical change is evaluated using equations 11 and 12 and the results are presented in Table 3. From the literature, biases less than one imply firms can reduce marginal cost by efficiently reallocating that variable. From Table 3 it can be seen that biases with PR/HACCP exist with labor use for small firms at the 5% significance level. PR/HACCP systems enable firms to change the way they do things and efficiently reallocate scarce resources. Translog cost function analyses indicated that cost functions were non-homothetic. This implies that technical change is due to both the Hicksian and scale effect.

Summary and Conclusion

This study applies a translog cost function to analyze how food safety expenses like PR/HACCP expenses affect the market for other inputs and output. The results show that the demand for these factors are inelastic, for all firm sizes. However, PR/HACCP significantly

impact the efficiency use of other inputs. Although PR/HACCP cost for small firms were higher, the analysis did not validate the hypothesis that PR/HACCP may impose significantly higher costs on firms to induce them to ineffectively implement (or exhibit moral hazard behavior) PR/HACCP systems. The results suggest that firm managers and federal agencies should continue educating employees about the essence of good management with PR/HACCP systems. The methodology developed in this paper was tested using the primary data collected from red meat processing and packing firms in the meat industry.

Efficiency analysis results indicate that HACCP can improve the overall efficiency of the meat industry by efficient reallocation of labor use and carcass purchases. These results are in conformity with prior findings of other statistical process control systems, which provide the basis for PR/HACCP systems. This study overcomes a major data limitation, to facilitate explicit economic impact analysis of PR/HACCP systems, by designing a primary survey instrument and working with the American Association of Meat Processors (AAMP) to facilitate data collection.

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Table 1. Parameter Estimates of the Translog Cost Function and Goodness of Fit Statistics

	All Firms	Small Firms
Constant	13.451***	10.752***
HACCP (HP)	0.0168	0.0411*
Carcass (CP)	0.0216**	0.2717
Labor(LP)	0.1819***	0.9890***
Material(MP)	0.1402*	0.2819
HP*HP	0.0092***	0.0114***
HP*CP	-0.0061	-0.0070
HP*LP	0.0021	0.0013
HP*MP	-0.0154**	-0.0072***
CP*CP	0.1819*	0.2333***
CP*LP	-0.1178***	-0.1369***
CP*MP	-0.0644	-0.0891***
LP*LP	0.0891**	0.0893
LP*MP	0.0263	0.0463**
MP*MP	0.0432	0.0452
Output(Y)	-0.6287***	-0.6081**
Y*HP	0.0087*	-0.0011
Y*CP	0.0690**	0.1050***
Y*LP	-0.0614***	-0.0561***
Y*MP	-0.0359	-0.0281
Y*Y	0.0720***	0.0611***
R ²	0.8667	0.9653
Homotheticity	6.3219***	22.8067
F-stats (P-value)	(0.0000)	(0.0000)

***, **, * Represent significance at the 1%, 5%, and 10% level of significance respectively. Because of symmetry restrictions the coefficients of the cost share equations are the same with the quadratic term coefficients

Table 2. Allen Elasticities of Substitution (AES) and Estimated Price Elasticities of Factor Demand at the Sample Mean

	Allen Elasticities of Substitution		Price Elasticities of Factor Demand	
	All firms	Small Firms	All Firms	Small Firms
HP*CP	0.4032	0.8563	-0.0086	-0.0182
HP*LP	-0.0593	0.0949	0.0013	-0.0020
HP*MP	0.0402	0.0053	-0.0016	-0.0001
CP*LP	6.4411	0.7407	-4.9474	-0.5689
CP*MP	3.8209	2.5166	-2.9348	-1.9330
MP*LP	-0.0978	0.1364	-0.0498	0.0695
HP*OP	0.9971	0.8375	0.5080	0.4267

Morishima Elasticities of Substitution (MES) and Effects of Factor Price Change on Cost shares at the Sample Mean

	Morishima Elasticities of Substitution		Effects of Factor Price Change on Cost shares	
	HP*CP	1.2914	2.3141	-0.2914
HP*LP	1.2275	0.75374	-0.2275	0.24626
HP*MP	1.3270	1.9120	-0.3270	-0.9120
CP*HP	2.9887	2.8425	-1.9887	-1.8425
CP*LP	2.7357	1.1144	-1.7357	-0.1144
CP*MP	0.1156	1.0402	0.8844	-0.0402
LP*HP	0.7001	2.8338	0.2999	-1.8338
LP*CP	2.5993	1.2036	-1.5993	-0.2036
LP*MP	3.0825	0.9561	-2.0825	0.0439
MP*HP	0.8362	2.8183	0.1638	-1.8183
MP*CP	0.6343	1.1359	0.3657	-0.1359
MP*LP	0.5618	1.0257	0.4382	-0.0257
HP*OP	0.9697	-0.0806	0.0303	1.0805

Table 3. Economies of Size Efficiency and Biased Technical Change of Input factors

	All Firms with	Small Firms	
Cost Efficiency (economies of size)	-1.2281	-2.3405	-1.6020
Biased Technical Change of Input factors			
HACCP (HP)		-	-0.0213
Carcass (CP)		1.2357	-0.7681
Labor(LP)		-1.4408*	1.2799
Material(MP)		1.2051	0.5095

* implies negative and significantly different from one at the 5% level of significance (example, 1 € -1.441 ± st. error(1.96)).

Endnotes

1. Other than the various certification regimes and current trends in labeling irradiated beef the market for food safety is not differentiated. This makes it difficult to evaluate the benefits of food safety systems like PR/HACCP.
2. From the definition of HACCP as a continuous, comprehensive food safety monitoring system that is designed to prevent hazards from developing and thus ensures a high degree of food safety (Karr et al.), several authors (Mazzocco; Nganje and Mazzocco; Scott et al.,) have discussed the similarities between HACCP and quality management systems. This premise supports the fact that HACCP can improve the efficiency of processes.
3. Prior to January 25, 2000 when all federal and state inspected firms fully adopted HACCP it may have been unrealistic for some firm managers to accurately report their HACCP expenses and perceived benefits because of their limited understanding of the HACCP mandate.
4. Taylor discussed other interesting pitfalls of the duality theory and possibilities to resolve them. The test for homotheticity and the model restrictions eliminate some specification errors.
5. The homotheticity test is a very important statistical test to determine production structure before bias technical change and economies of size can be measured. It serves as a robust test of the functional form used, and determines the direction of technical change and the magnitude of size efficiency (Karagiannis and Furtan1993).