The Cost of Food Safety Technologies in the Meat and Poultry Industries.

By

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Abstract

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This paper uses plant-level micro-data from the 2002 Census of Manufactures, Food Safety Inspection Service, and the Economic Research Service in a translog cost function to examine the costs of effort devoted to the performance of sanitation and process control tasks and levels of food safety technology use. Results suggest that more effort devoted to performance of sanitation and process control tasks and greater use of food safety technologies modestly reduce long run costs. These results suggest that plants that put forth effort to perform sanitation and process control tasks and plants with higher levels of food safety technology use have higher productivity and lower costs..

Keywords: food safety, food safety technologies, translog cost function, long run costs, meat and poultry industry.

The Cost of Food Safety Technologies in the Meat and Poultry Industries.

Roberts (2005) and Golan, et al. (2004) have argued that use of new food safety technologies in the meat and poultry industries can improve food safety process control. Golan, et al. (2004) also provides some anecdotal evidence suggesting that use of some technologies can improve processing yields and generate greater revenues. However, food safety technologies are used to ensure the safety of meat and poultry products and are not designed to raise productivity unless they constitute an automated system that replaces a manual one. Thus, if a food processing system is functioning properly, food safety technologies may be an added cost with no offsetting cost reductions.

The Food Safety Inspection Service (FSIS) has required plants to perform sanitation and process control tasks for many years and has recently required plants to identify, implement, and perform the additional sanitation and process control tasks necessary to maintain a Hazard Analysis Critical Control Point (HACCP) plan (Ollinger and Mueller, 2003). These sanitation and process control tasks are basic cleaning and sanitation requirements and process control procedures that may be necessary to ensure product safety and may improve product yields. As a result, performance of these tasks may or may not raise costs.

The purpose of this paper is to examine changes in long-run costs as the effort devoted to performing sanitation and process control tasks and the use of food safety technologies change. Previous food safety cost studies have focused on the costs of complying with the PR/HACCP rule of 1996. Of these, the cost studies most similar to this one are analyses by Antle, Nganje and Mazzocco, and Ollinger and Mueller who estimated costs of the Pathogen Reduction /Hazard Analysis Critical Control Point (PR/HACCP) rule of 1.3, 0.04 to 43.5, and 0.9 cents per pound of meat products. Other studies using a national survey (Ollinger, Moore, and Chandran) and regional surveys (Boland, Peterson-Hoffman, and Fox.; Hooker, Nayga, and Siebert) indicated costs of 0.7, 0.9, and 2 to 20 cents per pound, respectively.

This paper most closely tracks Ollinger and Mueller (2003) in that both papers use translog cost functions to estimate the costs of doing food safety tasks. The papers differ in three ways from the earlier paper. First the earlier paper examined only the cost of doing sanitation tasks, as mandated by the Food Safety Inspection Service, while this paper also includes process control tasks as described in HACCP plans. Second, this paper uses 2002 Census data and matching sanitation and process control data, both of which were collected after promulgation of the PR/HACCP rule. Data for the earlier paper came from the 1992 Census and matching FSIS data, which were collected before the PR/HACCP rule was mandated. Finally, this paper examines the impact of food safety technology on plant costs while the earlier paper did not.

THE REGULATORY ENVIRONMENT.

Concern over food safety and meat and poultry safety in particular and regulation of the meat and poultry processing industries has existed for over 100 years. However, only in recent years have the health threats posed *E coli*: 0157H7, *Listeria monocytogenes*, and other harmful pathogens become apparent (Ollinger and Mueller, 2003).

The most important recent FSIS food safety regulation came in 1996 when FSIS promulgated the final PR/HACCP rule. It mandated that (1) all meat and poultry plants must develop, implement, and take responsibility for standard sanitation operating procedures (SSOPs) and a HACCP process control program, (2) all slaughter plants must conduct generic *E. coli* microbial tests to verify control over fecal matter, and (3) all slaughter and ground meat plants comply with *Salmonella* standards under a program established and conducted by FSIS. Large plants (more than 500 workers) had to comply with the regulation by January 31 of 1998, and small (10-500 employees) and very small plants (and fewer than 10 employees with sales less than $2.5) had until January 31 in 1999 and 2000, respectively, to comply.

Under HACCP, plants had to develop a HACCP plan with associated SSOPs that outlined tasks required to implement the HACCP plan. plants also had to conduct sanitation, cleaning, and process control tasks, as required by the SSOPs. Some SSOPs were mandated by FSIS and some were under the discretion of the plant.

The Model

The goal of this paper is to evaluate the impact of the effort devoted to performing sanitation and process control tasks and the use of food safety technology on plant costs. Sanitation and process control tasks are jointly determined by the plant and FSIS in that the plant constructs sanitation and HACCP plans but these plans are subject to the approval of FSIS and many of the required tasks are monitored by FSIS inspectors. Nevertheless, since most plants have some tasks that are out of compliance, plants have some choice as to how much effort to put forth. If the mandated amount of effort exceeds that which is necessary to maintain food safety, then excessive costs are imposed on the plant. However, if the mandated mount of effort is less than that which a plant would do, then costs are not excessive.

Plant management determines the amount of food safety technology to use, i.e. there are no regulatory mandates. This technology could lower production costs if it reduces labor inputs or defective materials. Alternatively, it could raise production costs if it has no impact on meat or poultry yields and/or requires more workers to monitor operations.

Equation (1) links total plant production costs (C) to the prices of meat or poultry and other materials, labor, and capital (**P**), pounds of output (LB), a food safety technology index (T), and effort devoted to performing sanitation and process control tasks (S).

$$C = C(\mathbf{P}, LB, T, S)$$

Specification of the Empirical Model

In the empirical analysis, competitive factor markets are assumed and a translog cost function is used with food safety technology and effort entering the analysis separately. To ensure comparability, plant costs were evaluated separately for each of the industries – meat and poultry slaughter and meat processing -- because different industries have different product mixes, processing technologies, and other characteristics.

Economists have generally used one of two types of translog cost functions. Morrison (1999a, 1999b) and many others have used a multi-product cost function. In this approach, different products enter the analysis as separate variables. This method accurately captures differences in costs but requires that all plants produce all products specified in the model. If an observation has a zero entry for one of its products, then it cannot be evaluated because a translog cost function requires that all continuous variables be transformed to natural logarithms, which are undefined at zero. Since there are many meat and poultry plants that produce only one product or may not produce the two or more products specified in the cost function, many observations would have to be dropped if a multi-product translog cost function were used.

Economists (Allen and Liu, 1995) and many others in trucking and other transportation studies and MacDonald and Ollinger (2000, 2005) and Ollinger, MacDonald, and Madison (2005) in hog, cattle, and poultry slaughter analyses have accommodated multi-product plants with a single output translog cost function in which a single output is specified with a vector of output characteristics that describe that output. The advantage of this approach is that one model can be specified for both the single- and multi-product plants that may co-exist in an industry.

A single output, three factor translog cost function is specified in equation 2. The variables identified in equation 1 are included in the empirical model. Notice that there are no variables specifying characteristics for secondary products, as included in MacDonald and Ollinger (2000, 2005) and Ollinger, MacDonald, and Madison (2005). Models with characteristics were tested but they were dropped because they were not significant to model fit. That left equation (2) with prices, output, food safety technology use, and effort devoted to performing sanitation and process control tasks..

$$(2) \ln C = \alpha_0 + \sum_i \beta_i \ln P_i + \tfrac{1}{2}\sum_i \sum_j \beta_{ij} \ln P_i * \ln P_j + \gamma_{lb} \ln LB_{LB} + \tfrac{1}{2}\gamma_{LBLB} (\ln LB)^2$$

$$+ \sum_i \gamma_{LBi} \ln LB * \ln P_i + \delta_T \ln T + \frac{1}{2}\delta_{TT} (\ln T)^2 + \sum_i \delta_{Ti} \ln T * \ln P_i + \delta_{TLB} \ln T * \ln LB$$

$$+ \delta_S \ln S + \frac{1}{2}\delta_{SSi} \ln(S)^2 + \sum_i \delta_{Si} \ln S * \ln P_i + \delta_{SLB} \ln S * \ln LB + \xi$$

Greater efficiency can be obtained by estimating the cost share equations jointly with the cost function. Share equations are given by the derivative of the cost function with respect to input prices, as expressed in equation 3.

$$3)\quad \frac{\partial lnC}{\partial lnP_i} = \frac{P_i X_i}{C} = \beta_i + \sum_j \beta_{ij} \ln P_j + \gamma_{LBi} \ln LB + \delta_{Ti} \ln T + \delta_{Si} \ln S$$

Variable Definitions

The variables are defined as follows. Total cost (C) is the sum of labor, meat and materials, and capital input expenses. The price of labor (P_{labor}) is total employee wages and benefits divided by total employees. The meat and material input price (P_{mat}) is the cost of the live-weight of animals for slaughter plus any packed fresh or frozen meat or poultry plus materials divided by pounds of meat inputs. The price of capital ($P_{capital}$) follows Allen and Liu (1995) and MacDonald and Ollinger (2000, 2005), and Ollinger, MacDonald and Madison (2005). It has two components. The first is the weighted sum of machinery and building rental values, which equals rental prices for machinery and buildings divided by their respective book values. Annual capital rental prices are calculated by the Bureau of Labor Statistics separately for buildings and for machinery in the two-digit Food and Kindred Products Industry Group, using methods described in chapter 10 of the BLS Handbook of Methods, Bulletin 2490 and on the Multifactor Productivity Website (stats.bls.gov/mprhome.htm). The measures include components for depreciation, changes in asset prices, and taxes. Since the weights (book values of structures and equipment) differ across plants, capital prices are plant-specific. The second component adds the ratio of new investment to beginning of year assets, as a way to capture costs of adjustment.

Output (LB) equals pounds of meat and poultry products (all categories in SIC 201). The measure of food safety technology use comes from Ollinger, Moore, and Chandran (2004) and is an index value of food safety plant technology. It is a monotonic, continuous index value between zero and one. Plants with higher index values use more sophisticated equipment, do more frequent cleaning, have superior worker training systems, and/or have other practices and technologies that are superior in controlling pathogens than plants with lower index values. Data comes from 35 to 40 questions on five types of food safety technologies given in the ERS survey. The five technologies are: sanitation, operations, food safety processing equipment, plant capital investments, and hide removal technologies.

Sanitation and process control effort variable (S) equals the average of the number of sanitation tasks (SSOPs) in compliance with regulatory standards as a share of all SSOP tasks performed plus the number of HACCP process control tasks in compliance as a share of all HACCP tasks performed. Inspectors issue a noncompliance report for any required tasks that are not performed and maintain a database that has these noncompliance data and also the number tasks that were performed satisfactorily. The number and type of sanitation and process control procedures vary across plants. The types of procedures used in the definition were provided by Ron Eckel and other regulatory experts at the FSIS Omaha, Nebraska Technical Center.

Data

All variables, except capital rental prices, food safety technology, and food safety sanitation and process control tasks were obtained from the Longitudinal Research Database (LRD) maintained at the Center for Economic Studies of the U.S. Bureau of the Census. Data from the 2002 Census were used because that year come closest to matching the year when the ERS survey was conducted. Plants within the dataset were grouped into three industries with similar technologies: meat and chicken slaughter and processed products.

The LRD has data on all plants with more than 20 employees and a sample of those with less than 20 employees. The LRD notes each plant's ownership and location, and provides detailed information on employment, wages and benefits, building and machinery asset values, new capital expenditures, energy use and costs, the physical quantities and dollar sales of seven digit SIC code products, and the physical quantities and dollar expenses of detailed materials purchases.

Data for effort devoted to sanitation and HACCP process control tasks for 2001 came from FSIS. These regulatory compliance data include the number of SSOP sanitation and HACCP process control tasks out of compliance with FSIS standards, the number of tasks performed, and other process control data.

The Economic Research Service has a unique dataset containing information on plant characteristics, market relationships with buyers and sellers, and meat and poultry food safety technologies. The data were obtained in a survey containing approximately 40 questions on meat and poultry food safety technology, 15 questions on the costs of PR/HACCP regulation, various plant characteristics, and the types of markets plants serve. The 40 meat and poultry food safety responses were used to create five meat and poultry food safety technology indices: food safety equipment, food safety tests, hide-removal, sanitation, and food safety operating practices. Index values are higher for large and small plants with more intensive meat and poultry food safety activities. Refer to Ollinger, Moore, and Chandran (2004) for a complete description of the indices and the ERS survey.

The final dataset includes data from the LRD, FSIS regulatory compliance reports, and the ERS survey. Matching these data was a painstaking task requiring matches on names, zip codes, and outputs. The limiting dataset was that of ERS. It covered only establishments in the

EFD that ERS defined as manufacturers--about a third of the establishments inspected by FSIS[1]. Excluded establishments included retailers, wholesalers, and other nonmanufacturers. About 60 percent of the population of plants selected by ERS responded to the survey. These included 131 ground beef, 73 hog carcass, and 72 broiler plants that underwent *Salmonella* spp. testing in 2000 and 73 cattle carcass plants. Theses plants amounted to about 44 percent of the cattle and hog carcass and broiler plants and about 20 percent of the ground beef plants. The small number of ground beef plants is due to the wide diversity of establishments that grind meat. For example, many grocery stores and wholesalers grind meat as a side business. Additional plants were lost when matching the ERS/EFD data with the LRD.

The ERS survey was not nationally representative, meaning that results cannot be generalized. Two factors, however, suggest that the bias due to the use of a nonrepresentative sample is small.[2] First, the share of total output by respondents closely tracks the number of plants that participated in the survey, and a regression analysis by the authors suggests that no correlation exists between plant size and survey response. Second, the data were treated with a post-stratification adjustment (Gelman and Carlin, 2000) in which the regression is adjusted with a response weight equal to the reciprocal of the share of plants responding to the survey within each of eight size strata for each industry.

Estimation and Model Selection

1 The EFD identifies the primary Standard Industrial Classification (SIC) of all establishments. An establishment was assumed to be a manufacturer if it had a 2011, 2103, or 2015 SIC or slaughtered animals.
2 An anonymous reviewer asserts that a large degree of heterogeneity in the operations of establishments would increase the bias.

Estimation followed several common practices. First, symmetry and homogeneity of degree one were imposed on the model. Second, to simplify interpretation, all variables were normalized by dividing by their sample means. The first order input price terms, β_i, could then be interpreted as the estimated cost share at the sample means of the right-hand side variables. These cost shares vary as the right-hand side variables depart from their sample means. Notice also that the model regresses costs in current dollars on prices in current dollars; thus, there is no need to use deflators or other means to account for inter-temporal price variations due to inflation.

The system of equations includes the cost function and the cost share equations. Since costs shares sum to one, the capital share equation was dropped to avoid a singular covariance matrix (the coefficients of one equation, capital in this case, are implied by the other two equations). Finally, to take account of likely cross equation correlation and to achieve efficiency gains, the entire system of equations, including the cost function and the cost share equations, was estimated as a system with a nonlinear, iterative, seemingly unrelated regression procedure.

A four factor cost function that included separate entries for meat and materials was tested initially. However, the model failed monotonicity tests and was dropped. It was subsequently determined that the problem lie in the meat and materials data. The identity of total value of materials equal to the value of animal/meat plus material inputs is supposed to hold and did for analyses by MacDonald and Ollinger (2000, 2005) and Ollinger, MacDonald, and Madison (2005). However, the identity failed in the 2002 data. The poor data caused monotonicity tests to fail and required the use of three factor cost function with one variable (the price for total materials) equal the meat/liveweight animal input costs plus material costs divided by the weight of total meat/liveweight animal inputs, as defined earlier. Since materials are a small share of costs (MacDonald and Ollinger, 2000 and 2005; Ollinger, MacDonald, and Madison, 2005), the meat and materials term mainly reflects meat inputs.

The three factor model expressed in equation 2 is quite general with many possible variations. A number of economists, such as MacDonald and Ollinger (2000, 2005), Antle (2000), and Ollinger, MacDonald, and Madison (2005), faced a similar problem and used a Gallant-Jorgenson (G-J) likelihood ratio test (a chi-square test) to choose the best models from among sets of restrictive models. That same approach was followed here.

Table 1 gives a model number, description, test variables, and test, and the number of parameters estimated and restrictions, and the G-J value and model chi-square for meat and chicken slaughter and meat processing. Model testing was conducted in the following way. In each industry, we began by comparing the most restrictive version of equation 2 containing factor prices and output (P,LB) against least restrictive model (P,LB, T,S). Then, the least restrictive model is compared against models with one variable excluded to evaluate the impact of that one (removed) variable to model fit. Thus, in the first test, a base model consisting of prices and output is compared against a model that also contains the technology index and sanitation and process control effort. This test, a comparison of Model II with Model I, indicates that technology use and performance of sanitation and process control tasks are jointly significant in the meat slaughter and the meat processing industries but not in chicken slaughter. The test of Model III versus Model II indicates that technology is significant only in meat slaughter, and the test of Model IV versus Model II shows that sanitation and process control effort were significant in both meat slaughter and meat processing. Neither technology nor effort devoted to performance of sanitation and process control tasks were significant in poultry.

Results

How do cost function estimates compare to other studies?

The purpose of this research is to examine the impact of food safety technology and performance of sanitation and process control effort on plant costs. Before discussing the results, some model diagnostics are examined. First, notice that the R^2 statistics (bottom of table 2a) are a little lower than in other cost studies, but still quite high for a model using cross-sectional data. Second, tests of monotonicity show no violations of that condition. Third, since marginal costs are positive for all observations, there were no violations of the regularity condition.

The parameters on the first order price variables give factor cost shares in 2002 at the sample mean plant size and should be comparable to cost share estimates from other studies. Labor cost shares varied from 11.2 percent for meat slaughter to 19.9 percent for poultry slaughter and processing. Meat/material shares ranged from 79.5 for meat slaughter to 65.8 percent for meat processing and the capital cost share went from 9.4 percent in meat slaughter to 14.9 percent in meat processing.

The labor share for meat slaughter is about the same as that reported for hog slaughter in MacDonald and Ollinger (2000) and above that for cattle slaughter provided by MacDonald and Ollinger (2005). The poultry slaughter labor share is below that provided in Ollinger and MacDonald (2005). The meat/materials share for meat slaughter was between that for hog and cattle slaughter given in MacDonald and Ollinger (2000, 2005) and the poultry meat/materials share was similar to that for poultry shown in Ollinger and MacDonald (2005).

There are few comparable studies of the processing industries but its estimates can be compared to those for slaughter. More processing requires more labor and capital inputs and less meat, suggesting that the labor shares should be higher and the meat/materials share lower for meat processing. Results show that the labor and capital shares are much higher and the meat/materials share much lower for meat processing relative to meat slaughter. The meat processing labor share is about the same as that for chicken slaughter but this makes sense because chicken slaughter plants cut up whole chickens into parts and debone parts into boneless cuts and processing plants need worker for cutting, cooking, and packing finished processed products – all of which require more labor inputs than required for meat slaughter.

Recall that the coefficient on the output term indicates economies of scale at sample mean prices and output, i.e. whether average costs were declining for plants at the sample mean size. Values of the coefficient that are greater than one suggest diseconomies of scale while values less than one indicate greater scale economies. Since the first order coefficient for output varies from 0.721 to 0.921, there are economies of scale at sample mean prices in 2002. The coefficient for meat slaughter (0.921) is nearly the same as that reported for cattle slaughter and somewhat below that for hog slaughter (MacDonald and Ollinger, 2000, 2005). The size of the chicken slaughter coefficient is below that reported in Ollinger, MacDonald, and Madison (2005). There are no comparable economies of scale measures for meat processing.

The interaction terms show how elasticities and cost shares vary with movement away from sample means. The interaction of the price of labor with output shows how labor share changes with output. Table 2 shows a decline of 0.7- to 3.5 percent in the labor share for each 100 percent change in output; the meat shares, in contrast, rose by 0.9 to 3.4 percent. These changes suggest better use of labor as meat output rose – a finding consistent with MacDonald and Ollinger (2000,2005) and Ollinger, MacDonald, and Madison (2005).

Elasticities

The own price and Allen cross elasticities are reported in table A.1. All own price elasticities are negative, indicating downward sloping demand for inputs. Meat/materials was the most inelastic input but still more elastic than the meat alone elasticities reported in MacDonald and Ollinger (2000, 2005) Ollinger, MacDonald, and Madison (2005). The labor and capital own price elasticities are more elastic than meat/materials in all industries. Capital own-price elasticity ranged from -0.549 in meat processing to -0.790 in chicken slaughter and was quite similar to labor own-price elasticity, which varied from -0.388 in meat slaughter to -0.615 in chicken slaughter.

The Allen elasticity of factor substitution indicates the degree to which a given percent change in factor "k" can substitute for a percent change in factor "j". A higher positive number indicates greater substitutability. Values are reported in table A.1. Meat/materials and capital had the highest positive value, making them the strongest substitutes. Labor and capital are weak substitutes in meat processing and chicken slaughter but complements in meat slaughter. Meat/materials and labor are substitutes.

How do costs vary with food safety technology use and effort devoted to performing sanitation and process tasks and?

Table 3 gives mean values for the key variables. Table 4 shows changes in costs at sample mean values as effort devoted to performance of sanitation and process control tasks and the use of food safety technology changes from the 95th to the 5th percentiles. The table shows that there are no differences in costs due to differences in performance of sanitation and process control tasks for plants above the 75th percentile. Costs rise only modestly for plants in meat slaughter with performance in the 75th to the 5th percentiles and then jump dramatically at the 5th percentile. In meat processing and poultry, cost rises from their 75th percentiles to the mean performance of sanitation and process control tasks is followed by no change in costs for meat processing and a small cost increase in poultry slaughter before both rise sharply between the 25th and 5th percentile.

The results for the performance of sanitation and process control tasks are surprising. Intuitively, greater effort devoted to the performance of sanitation and process control control tasks should lead to higher costs because more labor must be expended to complete a higher percentage of tasks. Lower costs with better performance of sanitation and process control tasks implies that (1) higher task performance of sanitation and process control leads to higher productivity or (2) the sample is biased.

To see if the sample is biased, a model containing the tasks variable but not the technology index was examined. This model permitted a near doubling of the sample sizes for each industry since observations without the technology index did not have to be dropped. We do not report coefficients but do provide the mean values (table 3b) and show how costs change with changes in the percentile of task performance (table 4, bottom panel). Results are consistent with the findings using the smaller set of data, except that the rise in costs over the 5th to 25th

percentile is not as dramatic. Thus, it does not appear that the results from the smaller sample are biased.

The pattern for technology is similar to performance of sanitation and process control tasks in meat slaughter and meat processing. There is a modest increase in costs over the 95th to 25th percentile in cattle slaughter and nearly no change in costs for meat processing. Poultry slaughter and processing has a steep rise in costs over the 95th to 25th percentiles, rising by more than about two-thirds. Over the 25th to 5th percentile, however, costs drop dramatically. This drop in costs is likely due to the nature of these plants' business. Poultry plants requiring little advanced food safety technology typically produce specialty products for niche markets that require minimal processing, lowering production costs.

Results for the technology index suggest that food safety technology reduces costs for meat slaughter, meat processing, and all but the very smallest poultry slaughter plants. Food safety technology can be cost-reducing if an automated technology replaces a manual one or production yields increase. Cost trends for poultry slaughter plants with below average technology levels may be due to differences in plant technology – large poultry plants are highly automated while small ones are not. See Antle (2000) for a discussion. The smaller cost changes for meat processing relative to meat slaughter might be due to fewer technology options being available to processing plants relative to slaughter plants.

CONCLUSION

There has been considerable concern that a greater emphasis on the provision of food safety, particularly through regulation, would raise manufacturing costs. Antle (2000), for example, suggested the costs of food safety regulation under the PR/HACCP rule would be more than $0.01 per pound.

This paper uses a translog cost function to examine the cost of effort devoted to performing sanitation and process control tasks and the cost of using food safety technologies in the meat slaughter, meat processing, and poultry slaughter and processing industries in 2002. Results suggest that greater effort devoted to the performance of sanitation and process control tasks and more use of food safety technologies reduce costs. Results for food safety technology were significant in meat slaughter; results for effort devoted to the performance of sanitation and process control tasks were significant in meat slaughter and meat processing. Neither food safety technology nor the performance of sanitation and process control tasks was significant in poultry slaughter.

Simulations of the cost function were used to show the direction of cost change and to evaluate consistency across the industries. Those simulations show steadily rising costs from the 95^{th} to the 5^{th} percentile for effort devoted to the performance of sanitation and process control tasks in all industries and for the use of food safety technologies in meat slaughter and meat processing. Poultry slaughter and processing had higher costs associated with lower percentiles of technology use over the 95^{th} to 25^{th} percentiles but not afterward.

Findings that better performance of sanitation and process control tasks and greater use of food safety technology are associated with lower costs are not surprising. Companies maintain quality control departments and invest in food safety technologies to maintain control over product quality, avoid product recalls, and increase product shelf life. Staffing these quality control departments may be costly but do not have to excessive because plants choose their own sanitation and process control tasks and can use a food safety technology that matches their production system. Moreover, better food safety quality control may offset added food safety costs while reducing other costs by improving production yields and reducing product rework by production staff. Thus, it could be that plants in the lower percentiles of performance of sanitation and process control tasks and food safety technology underinvest in food safety and pay a cost of lower production yields and higher costs.

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Table 1: Goodness of fit and model selections of the best meat or poultry cost function models.

Industry	Model Number	Description	Test Variable	Test	Parameters Estimated	Restric-tions	G-J Value	Model Chi-Square
Meat Slaughter	I	P,LB[1]		-	10	-	186.6	-
	II	(P,LB,S,T)[2]	Both (T,S)	I vs II	21	11	159.5	27.1***
	III	(P,LB,S)[3]	Technology (T)	II vs. III	15	6	171.5	12.0*
	IV	(P,LB,T)[4]	Sanitation and Process Control (S)	II vs. IV	15	6	173.4	13.9*
Meat Processing	I	P,LB[1]		-	10	-	586.8	-
	II	(P,LB,S,T)[2]	Both (T,S)	I vs II	21	11	555.9	30.9***
	III	(P,LB,S)[3]	Technology (T)	II vs. III	15	6	563.8	7.9
	IV	(P,LB,T)[4]	Sanitation (S)	II vs. IV	15	6	574.2	18.3***
Poultry Slaughter	I	P,LB[1]		-	10	-	126.4	-
	II	(P,LB,S,T)[2]	Both (T,S)	I vs II	21	11	113.6	12.8
	III	(P,LB,S)[3]	Technology (T)	II vs. III	15	6	121.1	7.5
	IV	(P,LB,T)[4]	Sanitation (S)	II vs. IV	15	6	119.1	5.5
	Regu-lation							
Meat Slaughter	I	P,LB[1]		-	10	-	417.0	-
	III	(P,LB,R)[3]	Sanitation (S)	I vs. III	15	5	410.0	7.0
Meat Processing	I	P,LB[1]		-	10		1,278	-
	III	(P,LB,R)[3]	Sanitation (S)	I vs. III	15	5	1,228	50.0***
Chicken Slaughter	I	P,LB[1]		-	10		348.3	-
	III	(P,LB,R)[3]	Sanitation (S)	I vs. III	15	5	332.6	15.7**

* significant at the 90% level, ** significant at the 95% level, *** significant at the 99% level

1 Model I: base model consisting of prices (P) and pounds of output (LB) and denoted (P,LB).

[2] Model II: Adds technology (T) and sanitation and process control (S) to (P,LB) to make (P,LB,S,T).

[3] Model III: Removes T from II to make (P,LB,S).

[4] Model IV; Removes S from II to make (P,LB,T).

Table 2a: Meat and poultry industry cost function parameter estimates.

Variable	-----------------------------Industry-----------------------		
Variable Name	Meat Slaughter	Meat Processing	Poultry Slaughter
Intercept	0.056 (0.085)	0.267*** (0.079)	0.193*** (0.071)
P_{labor}	0.112*** (0.008)	0.193*** (0.008)	0.199*** (0.008)
P_{meat}	0.794*** (0.018)	0.658*** (0.013)	0.695*** (0.012)
$P_{capital}$	0.094*** (0.015)	0.149** (0.008)	0.106*** (0.010)
LB	0.925*** (0.055)	0.775*** (0.050)	0.721*** (0.085)
T	-0.145 (0.569)	0.112 (0.227)	-0.108 (0.274)
S	-1.427 (3.275)	-9.350* (5.292)	-2.000* (1.234)
P_{labor} *P_{labor}	0.056*** (0.020)	0.059*** (0.016)	0.037 (0.031)
P_{meat} *P_{meat}	-0.054* (0.030)	0.051** (0.023)	0.037 (0.036)
$P_{capital}$ *$P_{capital}$	0.016	0.045	0.011
P_{labor}*P_{meat}	0.007 (0.012)	-0.032** (0.014)	-0.032*** (0.010)
P_{labor}*$P_{capital}$	-0.063*** (0.021)	-0.027 (0.027)	-0.005 (0.029)
P_{meat}*$P_{capital}$	0.047* (0.025)	-0.018*** (-1.330)	-0.006 (0.027)
R^2	0.91	0.77	0.78
Observations	97	219	57

* significant at the 90% level, ** significant at the 95% level, *** significant at the 99% level

Table 2b Meat and poultry industry cost function parameter estimates: Second order output, food safety technology terms, and sanitation and process control terms.

Variable	----------------------------Industry-----------------------		
Variable Name	Meat Slaughter	Meat Processing	Poultry Slaughter
LB*LB	-0.004 (0.033)	0.022 (0.027)	-0.055 (0.071)
LB*P_{labor}	-0.007* (0.004)	-0.009** (0.004)	-0.035*** (0.010)
LB*P_{meat}	0.011 (0.012)	0.010* (0.006)	0.045*** (0.015)
LB* $P_{capital}$	-0.002 (0.007)	-0.001 (0.003)	-0.010 (0.012)
T*T	0.349 (0.745)	-0.680 (0.446)	-5.726** (2.134)
T*P_{labor}	-0.015 (0.020)	0.018 (0.016)	0.075* (0.042)
T* P_{meat}	0.014 (0.048)	-0.017 (0.025)	-0.101* (0.0622)
T* $P_{capital}$	0.001 (0.040	-0.001 (0.016)	0.026 (0.049)
T*LB	0.013 (0.100)	0.071 (0.086)	0.249 (0.336)
S*T	-8.691 (6.446)	-9.773 (8.220)	1.060 (6.707)
S*S	53.26 (66.68)	-320.0** (157.0)	-5.619 (23.72)
S*P_{labor}	0.136 (0.182)	-0.094 (0.365)	0.121 (0.146)
S* P_{meat}	-0.132 (0.437)	0.406 (0.570)	-0.192 (0.217)
S* $P_{capital}$	-0.004 (0.370)	-0.312 (0.352)	0.071 (0.169)
S*LB	0.514 (1.268)	1.392 (1.676)	1.373 (1.760)
R^2	0.91	0.77	0.78
Observations	97	219	57

* significant at the 90% level, ** significant at the 95% level, *** significant at the 99% level

Table 3a: Selected means of variables in the cost function models of the meat and poultry industries: Dataset includes the technology index.[1]

Variable	----------------------------Industry----------------------		
	Meat Slaughter	Meat Processing	Poultry Slaughter
Sanitation and Process Control Performance	0.966	0.984	0.931
Technology Index Value	0.581	0.561	0.619
Wages ($1000s/year)	32.12	37.31	24.79
Price of Capital ($)	0.368	0.375	0.374
Price of Meat Inputs ($/lb.)	0.788	1.104	0.364
Total Costs ($1000)	24, 872	2,983	10,599
Total Pounds of Output (1000 lbs.)	37,256	2,592	19,704
Labor Cost Share	0.118	0.205	0.207
Meat Cost Share	0.796	0.642	0.686
Capital Cost Share	0.086	0.153	0.107
Observations	97	219	57

1. Observations without a technology index value were dropped, eliminating some observations.

Table 3b: Selected means of variable in the cost function models of the meat and poultry industries: Full dataset, i.e does not include the technology index.

Variable	----------------------------Industry----------------------		
	Meat Slaughter	Meat Processing	Poultry Slaughter and Processing
Sanitation and Process Control Performance	0.969	0.985	0.931
Wages ($1000s/year)	31.74	35.67	24.18
Price of Capital ($)	0.369	0.367	0.376
Price of Meat Inputs ($/lb.)	0.790	1.141	0.376
Total Costs ($1000)	243,918	29,533	97,725
Total Pounds of Output (1000 lbs.)	379,792	23,370	198,025
Labor Cost Share	0.120	0.209	0.209
Meat Cost Share	0.794	0.639	0.677
Capital Cost Share	0.086	0.152	0.114
Observations	199	470	143

Table 4: Cost index values evaluated at sample mean values and at selected percentiles of food safety technology use and performance of sanitation and process control tasks.[1]

Industry	Variable	-----Percentile-----		--Mean---	------Percentile------	
		95	75		25	5
Model: Food safety technology use and performance of sanitation and process control tasks.						
Meat Slaughter	Sanitation and Process Control	0.99	0.99	1.00	1.02	1.11
Meat processing	Sanitation and Process Control	0.90	0.90	1.00	1.00	1.15
Poultry Slaughter and Processing	Sanitation and Process Control	0.89	0.90	1.00	1.04	1.29
Meat Slaughter	Technology	0.97	0.98	1.00	1.05	1.24
Meat processing	Technology	0.99	1.01	1.00	1.01	1.18
Poultry Slaughter and Processing	Technology	0.76	0.96	1.00	1.28	0.62
Model: Performance of sanitation and process control tasks only, no food safety technology.						
Meat Slaughter	Sanitation and Process Control	0.92	0.92	1.00	1.04	1.12
Meat processing	Sanitation and Process Control	0.89	0.89	1.00	1.00	0.99
Poultry Slaughter and Processing	Sanitation and Process Control	0.87	0.90	1.00	1.03	1.02

[1]Costs were estimated for sanitation and process control task and food safety technology by allowing S and T to vary and setting all other values at their sample means. Most terms drop out and we are left with: $\ln C = \text{Intercept} + \beta_s \ln S + \beta_{S2} \ln S * \ln S$ and
$\ln C = \text{Intercept} + \beta_T \ln T + \beta_{T2} \ln T * \ln T$.

Table A.1: Input Shares and Own Factor Price Elasticities in the Meat and Poultry Industries.

			-----------------Price--------------		
Industry		Price	Labor	Meat/ Materials	Capital
Meat Slaughter	Input Share		0.112	0.794	0.094
	ε_{ij} (Own price elasticity)		-0.388	-0.274	-0.735
	σ_{ij} (Allen cross elasticity)	Labor	-3.464	1.079	-4.984
		Meat/Materials	-	-0.345	1.629
		Capital	-	-	-7.819
Meat Processing	Input Share		0.193	0.658	0.149
	ε_{ij} (Own price elasticity)		-0.501	-0.264	-0.549
	σ_{ij} (Allen cross elasticity)	Labor	-2.596	0.748	0.061
		Meat/Materials		-0.401	0.816
		Capital			-3.684
Chicken Slaughter	Input Share		0.199	0.695	0.106
	ε_{ij} (Own price elasticity)		-0.615	-0.252	-0.790
	σ_{ij} (Allen cross elasticity)	Labor	-3.090	0.769	0.567
		Meat/Materials		-0.363	0.837
		Capital			-7.453