The Impact of Market Mechanisms and HACCP Regulation on Food Safety Quality.

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Selected paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, Denver, Colorado, August 1-4, 2004.

* The judgments and conclusions herein are those of the author and do not necessarily reflect those of the U.S. Department of Agriculture. The author is responsible for any errors.

ABSTRACT

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Economists have long debated the relative effectiveness of markets and regulations in reaching socially desirable outcomes. This empirical study of meat and poultry food safety regulation suggests that market mechanisms and flexible regulatory instruments, e.g. HACCP systems, have a greater impact on food safety quality than less flexible regulatory instruments.

Subject code: 9 (Food Safety and Nutrition).

The Impact of Market Mechanisms and HACCP Regulation on Food Safety Quality.

Economists have long debated the relative effectiveness of market mechanisms and regulatory instruments in reaching socially desirable outcomes. Antle (1996) and many other economists reluctantly argue that food safety regulation may be justified because buyers cannot directly evaluate pathogen levels before or after purchase and third parties cannot unambiguously certify quality because the costs of acquiring pathogen information is prohibitive. In the absence of these traditional market mechanisms, large restaurant and grocery store chains have imposed their own food safety quality control programs on suppliers (Ollinger and Mueller, 2003). These buyers have strong incentives to impose standards because they can spread the associated costs over millions of pounds of product sales and an outbreak of a foodborne illness attributed to them could cause them to lose their reputations, resulting in a catastrophic drop in profits.

Large buyers that are able to impose sophisticated quality control programs on suppliers account for only a small fraction of the meat and poultry market and even they may not know the pathogen levels of the meat products they sell. Since buyers that do not require pathogen testing and some that do require it do not know the pathogen levels of the meat they buy, food safety quality remains an important public health concern of the U.S. government and has led the Food Safety Inspection Service (FSIS) of USDA to promulgate the Pathogen Reduction Hazard Analysis Critical Control Point Regulation (PR/HACCP) rule in 1996. This regulation mandates that all plants must establish and implement standard sanitation operating procedures (SSOPs) and a HACCP process control program, slaughter plants must adhere to generic *E. coli* standards, and slaughter and ground meat plants must comply with *Salmonella* standards. The SSOPs are cleaning, sanitation, and process control tasks that plants must perform in order to be in compliance with FSIS regulations. Plants develop and implement their own HACCP programs but are subject to FSIS oversight.

The SSOPs mandated in the PR/HACCP rule reflected a continuation of a previous regulatory regime of process standards in which FSIS mandated and monitored specific tasks. If plants completed the tasks, then they were in regulatory compliance. Under the HACCP programs, FSIS took a different approach in that plants specified and implemented their own program. FSIS, however, ensured that plants complied with their HACCP plans. Antle (2001) classified SSOPs and HACCP programs as design standards because they require certain tasks to be performed. Pointing out that HACCP programs are much more flexible than SSOPs since they are tailored to meet the unique circumstances of each plant, Coglianese and Lazer (2002) label HACCP programs as a management-based regulation.

The generic *E. coli* and *Salmonella* standards mandated under PR/HACCP marked a significant departure from prior regulatory practices at FSIS. Under these performance standards, plants must meet microbiological tolerances. As long as the tests indicate that the plant is within tolerances, then it is considered to be in regulatory compliance. Plants could use whatever approach they deemed necessary to meet the standard. Antle (2001) and many other economists favor performance standards over design standards and management-based regulations because, due to their flexibility, they are considered to be a less costly way to comply with a regulation. In a similar way, the flexibility offered by a management–based regulation should make this preferable to a stricter design standard that inhibits innovation.

The purpose of this paper is to examine the impacts of large buyers, process regulatory standards, and management-based regulatory standards on food safety performance. We use the number of positive *Salmonella* test samples as a share of all samples examined by FSIS as a measure of food safety performance. The analysis requires the use of unique datasets from FSIS and the Economic Research Service of USDA. The FSIS datasets provide information about the plant-level number of meat and poultry samples testing positive for *Salmonella,* the number of samples tested for *Salmonella,* and plant performance of SSOP and HACCP tasks. FSIS data also contains information about animals slaughtered and some production data. The ERS data provides information on plant-level food safety technologies, whether plants have large customers that influence their production practices, and plant characteristics.

Meat and Poultry Food Safety and the Regulatory Environment

FSIS promulgated the final PR/HACCP rule on July 25, 1996. The principal element of the PR/HACCP rule was the requirement to develop and implement HACCP process control programs for each FSIS-defined product produced by the plant. HACCP programs are based on these seven criteria: (1) assessing all hazards, (2) finding all critical points, (3) setting critical limits for each critical control point (CCP), (4) developing procedures to monitor each CCP, (5) determining corrective actions, (6) implementing a recordkeeping system, and (7) establishing verification procedures (Unnevehr and Jensen,1996).

There were other important components of the PR/HACCP rule. The regulation required meat and poultry establishments to develop, implement, and take responsibility for performing SSOPs. Second, it mandated that slaughter plants conduct generic *E. coli* microbial tests in order to verify that fecal contamination was under control. Finally, in order to verify that their HACCP systems were controlling pathogens, the PR/HACCP rule established *Salmonella* performance standards for slaughter and ground meat and poultry plants.

PR/HACCP was phased in over several years. All plants had to comply with the HACCP requirement by January 31, 2000. Large plants were required to implement their programs by January 31, 1998, followed by small and very small plants over the next two years. All plants had to have their SSOPs in place by January of 1997.

Pathogen testing marked a sharp departure from previous regulatory practices at FSIS because it required plants to meet standards without specifying how to reach the objective. Under the generic *E. coli* standard, plant testing requirements depended on production volume. Cattle slaughter plants, for example, have to take one sample per 300 carcasses, while broiler plants are required to take one sample per 22,000 birds. Plants failing to meet the generic *E. coli* standard had to discover and correct the cause of the failure or face increased FSIS scrutiny of facilities, products, and plant compliance with their HACCP plan and SSOPs. FSIS may also perform more product testing. If plant performance is deemed unsatisfactory, FSIS can remove its inspectors.

FSIS uses *Salmonella* tests as a measure of overall plant food safety process control, and can deem a failure to meet the standard as one of the bases for declaring a product to be adulterated. Under this program, FSIS randomly selects plants for testing and then tests plants products (ground meat or carcasses) for *Salmonella* over a series of days. A plant that exceeds the maximum allowed number of positive *Salmonella* samples must complete a second round of tests after it modifies its food safety process control program. If the plant fails that round, then, it again modifies its process control program and undergoes another round of testing. Failure to pass on the third attempt constitutes failure to maintain sanitary conditions and maintain an adequate HACCP plan and will cause FSIS to suspend inspection services. The suspension remains in effect until the plant submits a detailed action plan to correct the HACCP plan and outlines the other measures taken by the plant to reduce the prevalence of pathogens.

It has been rare for plants to fail *Salmonella* compliance testing. Only about 100 out of the approximately 2,050 slaughter and grinding plants tested up to 1999 failed to pass the first test and only 22 of these 100 plants failed their first two tests. Failure to comply after two tests would have led to increased enforcement review, but 19 of these plants passed the third test and continued production. These 19 plants included 1 for ground turkey and 7 for ground beef, and 4 hog slaughter, 6 broiler slaughter and 2 cow and bull slaughter plants. Supreme Beef and one other ground beef plant and one cow/bull slaughter plant failed three tests, and FSIS suspended them, meaning that plants retained the right to inspection services if the suspension was lifted.

Economic Framework

We hypothesize that plant characteristics, food safety technology, performance of regulatory tasks, and the influence of large buyers affect *Salmonella* test performance. Plant characteristics describe the size, scope, and complexity of a plant's processing technology. Food safety technologies include the equipment and procedures designed and adopted by plants for the purpose of controlling pathogens. These technologies either kill pathogens directly by heat or chemical treatments or reduce the opportunity for product contamination through changes in operations or more intensive cleaning.

Plants are required to comply with Standard Sanitation Operating Procedures (SSOPs), a Hazard Analysis Critical Control Point (HACCP) program, and maintain facilities according to FSIS specifications. Plants write their own SSOP and HACCP plans and are expected to perform all the functions specified in their plans. FSIS monitors plants and notes when plants fail to comply. Since the SSOPs and HACCP plans specify practices that are designed to control pathogens, deviations from the plan may result in a higher incidence of pathogens in meat and poultry products.

Major buyers of a company's products exert control over production practices in a variety of ways ranging from specifying technologies to refusing orders that may be of questionable quality. We express food safety performance as function of plant characteristics (CHAR), food safety technology (FSTECH), regulatory compliance (REG), and major buyers on food safety performance (MARKET) in equation 1.

PERF = (CHAR, FSTECH, REG, MARKET)   (1)

where PERF is a number from zero to one indicating the share of samples testing positive for Salmonella in FSIS *Salmonella* testing program described above.

Empirical Specification

The dependent variable, PERF, is the number of positive test samples as a share of all test samples, making it an index bounded below by zero (plants with no samples testing positive for *Salmonella*) and bounded above by one (plants with all samples testing positive for *Salmonella*). In practice, many plants had no reported positive cases of *Salmonella* but no plant had only *Salmonella* positive cases, making the real distribution bounded from below but not from above.

For purposes of the analysis we assume that PERF has a normal distribution centered around and truncated at zero, meaning that, if it were possible, some values would be less than zero. Plants that fall in this truncated region are those plants that are particularly concerned about their reputations for food safety and want to ensure that none of their products are contaminated.

Tobin (1958) was the first to consider regressions with censored dependent variables. He specified a dependent variable with a distribution centered at zero that contained a theoretically possible latent variable (y*). Greene (1993) gives the following general formulation of the censored regression model, also known as the Tobit model:

$$y_i^* = \beta' x_i + \varepsilon_i \qquad (2)$$

$$y_i = 0 \text{ if } y_i^* \leq 0$$

$$y_i > 0 \text{ if } y_i^* > 0$$

Applying equation 2 to equation 1 means that the distribution for y_i^* is the percent samples testing positive for *Salmonella*. A positive coefficient on an independent variable (a plant characteristics, technology, regulatory, or market variable in equation 1) means that the independent variable (x_i) encourages positive *Salmonella* test samples and a negative value means that x_i decreases the likelihood of a positive *Salmonella* test sample.

Marginal effects, as illustrated in equation 3, indicate by how much a change in an independent variable affects the likelihood of testing positive for *Salmonella*.

$$\partial E[y_i^* \mid x_i] / \partial x_i = \beta \qquad (3)$$

Typically, marginal effects, which show how marginal changes in the independent variables affect the dependent variable, can be obtained by taking a derivative of the regression equation, as shown in equation 3. However, since *Salmonella* test performance occurs only in the positive portion of the distribution, an alternative specification, equation 6, is required. As always, the sign and size of the coefficient indicates how much the independent variable affects the dependent variable. Greene's (1993) derivation of the marginal effects follows:

$$E[y_i \mid x_i] = \Phi(\beta' x_i / \sigma)(\beta' x_i + \sigma\lambda_i), \qquad (4)$$

where

$$\lambda_i = \phi(\beta' x_i / \sigma) / \Phi(\beta' x_i / \sigma), \qquad (5)$$

and the marginal effect of the independent variables on y_i is:

$$\partial E[y_i \mid x_i] / \partial x_i = \beta\Phi(\beta' x_i / \sigma). \qquad (6)$$

Note, σ is the standard deviation, ϕ is the probability density function of the standard normal distribution, and Φ is the cumulative density function of the standard normal distribution.

Below, we empirically represent our model.

$$PERF_i = \beta_0 + \sum_{g=1}^{g=q} \gamma_{ig} CHAR_{ig} + \sum_{h=1}^{h=p} \phi_{ih} FSTECH_{ih} + \sum_{j=1}^{j-n} \alpha_{ij} REG_{ij} + \sum_{k=1}^{k=m} \chi_{ik} MARKET_{ik} + \varepsilon_i \qquad (7)$$

where the variables have been defined above and

$PERF_i$ (share of samples testing positive for *Salmonella*) = 0, if $PERF_i^* \leq 0$,

$PERF_i$ (share of samples testing positive for *Salmonella*) > 0, if $PERF_i^* > 0$.

The mean of $PERF_i^*$, a theoretically normally distributed dependent variable, is less than the mean of $PERF_i$ because $PERF_i$ cannot be less than zero. The independent variables represented by CHAR are plant characteristics, such as plant size and whether the plant slaughters animals. The impact of these variables on the share of samples testing positive for *Salmonella* depends on whether the characteristic adds to the complexity of plant operations or encourages food safety investments. Greater complexity due to an increase in plant operating procedures makes the control of pathogens more costly due to higher management costs. Greater economies of scale, on the other hand, may lower the cost of food safety investments. Larger size plants, for example, can reduce per unit food safety costs by spreading expenditures for new food safety equipment over a larger production volume.

FSTECH represents five types of food safety technologies: sanitation procedures (not SSOPs), operating practices, product and environmental testing, equipment, and, for cattle slaughter plants, dehiding practices. A negative relationship should exist if a technology is effective in reducing the number of positive *Salmonella* samples.

REG is the influence of various FSIS regulatory instruments, e.g. SSOPs and HACCP plans. Better performance of SSOPs or a plant's HACCP program should lead to fewer positive *Salmonella* test samples. MARKET is a dummy variable for different types of market mechanisms k. These mechanisms include relationships between plants and large buyers, like McDonalds, linkages between plants and export markets, and whether the plant produces a product under a brand name. MARKET should negatively affect the number of positive *Salmonella* test samples.

Variable Definitions

We defined the dependent variable, PERF, above. There are several plant characteristics variables. Large plants may be able to achieve economies of scale in food safety technology, making it easier for them to control pathogens, but they are also more complex than small plants, causing greater difficulty in controlling pathogens (Havelaar, Nauta, and Jansen, 2004). As a measure of plant size, we use the log of pounds of plant output, Log (POUNDS). We also control for multi-species plants because they are more complex than single-species plants, perhaps, making them more difficult to manage and less able to control pathogens. Empirically, we use a dummy variable indicating whether the plant slaughters more than one animal species, e.g. cattle and hogs, (MULTI-SPECIES). Plants that slaughter animals and grind and cook meat or poultry are much more complex than single process plants; thus, we controlled for them. We are uncertain of the signs because they may have offsetting incentives. For example, a plant that both slaughters animals and grinds meat may be more cautious about controlling pathogens than a plant that simply slaughters animals because grinders may get feedback directly from consumers about food safety quality while a carcass producer may not. To control for grinding operations in a slaughter plant, we define GROUND as a dummy variable equal to one if the plant grinds meat and zero otherwise. For plants that cook or further process meat or poultry, we define COOKED as dummy variable equal to one if the plant cooks or further processes meat or poultry and zero otherwise. Finally, for ground beef plants we define SLAUGHTER as a dummy variable equal to one if the plant slaughters animals and zero otherwise.

The food safety technology variables for cattle slaughter are DEHIDE_TECH, an index value between zero and one describing the sophistication of plant dehiding technology, DEHIDE_KNIFE, a dummy variable indicating whether the plant sanitize knives or rotate knives after slaughtering each animal. One of the food safety technology variables for broilers is dummy variable for whether the plant uses a modern eviscerator (EVISCERATOR). One of the food safety technology variables for hogs is STEAM_VAC (a dummy variable equal one for plants that use steam vacuum machines for hogs). For broiler, hogs, and ground beef an additional food safety technology variable is a dummy variable for plants with plant food safety operating procedures rated to be in the 90^{th} percentile on an index rating the intensity of food safety production practices (see the data section for further discussion). A final food safety technology variable for poultry and hog slaughter is a dummy variable indicating whether a plant removes the animal from feed prior to slaughter (NOFEED).

A regulatory variable for all plants is the number of inspected HACCP tasks not in compliance with HACCP plan requirements as a share of all HACCP tasks (HACCP_NOCOMPLY). For all industries except cattle slaughter, another regulatory variable is the number of SSOP tasks not in compliance with the SSOP plan as a share of all SSOP tasks (SSOP_NOCOMPLY).

The market influence variables for poultry and hog slaughter and ground beef (CUSTOMER_SPECS) is a dummy variable equal to one for plants subject to requirements from a domestic customers and zero otherwise while the market influence variable for cattle slaughter is one for plants that export and zero otherwise (EXPORT). We included only one market mechanism variable in each regression. The choice depended on which type of market would likely have the greatest influence on production practices. Export markets may be more important for cattle slaughter plants than for the other plants because cattle carcasses are far removed from consumers and beef exports amount to about 10 percent of output. Both hog slaughter and broiler plants have extensive further processing operations within their plants, thus, these plants and ground meat producers sell most of their products to domestic buyers that sell to consumers. The large domestic buyers have substantial influence over their suppliers due to their large volume purchases.

Data

Data comes from the Food Safety Inspection Service (FSIS) and Economic Research Service (ERS). One of the FSIS datasets provides data on the two pieces of information needed to compute the share of samples testing positive for *Salmonella.* Among other data, this dataset includes the total number of test samples and the number of test samples found to be positive for *Salmonella* by FSIS personnel in randomly selected plants in the year 2000. For cattle slaughter, we also used 2001 data because FSIS tested only 40 plants producing carcasses in 2000.

Another of the FSIS datasets, also obtained in a personal communication, contains data on the number of SSOP and HACCP tasks out of compliance with the plant SSOP or HACCP plan. Each plant inspected by FSIS is required to have SSOP and HACCP plans that specify certain key points that should be monitored and maintained. Since the number of SSOP and HACCP tasks varies by plant, we divided by the number of tasks not in compliance with SSOP and HACCP standards by total number of tasks to create variables for the shares of tasks out of compliance with SSOP and HACCP requirements.

The FSIS data also contains the number of facility requirements established by FSIS that are out of compliance with FSIS specifications. However, this variable was later dropped because it had little impact on *Salmonella* test performance.

Some observers of FSIS inspection activities believe that variance exists in the way inspectors measure the performance of food safety tasks. While this may be the case, we have no reason to believe that there is a systematic bias in these data. Thus, it appears unlikely that random reporting differences will affect statistical results.

The final FSIS dataset used in the analysis is the Enhanced Facilities Database (EFD) for 2000. This dataset contains detailed information on the numbers and types of animals slaughtered, SIC codes, pounds of meat or poultry produced, whether a plant produced meat or poultry, and categorical data on process types for each plant inspected by FSIS.

The Economic Research Service has a unique dataset containing information on plant characteristics, market mechanisms and food safety technologies. The data were obtained in a survey containing approximately 40 questions dealing with food safety technology, 15 questions on aspects of the costs of the PR/HACCP regulation, various plant characteristics, and the types of markets plants serve. The 40 food safety responses were used to create five types of food safety indices: food safety equipment, food safety tests, dehiding, sanitation, and food safety operating practices. The index values more intensive food safety activities higher than less intensive ones. Thus, a plant with the highest food safety equipment rating (one) would have all the types of equipment dealt with by the survey while a plant with a zero rating would have none of the equipment. Plants with a partial number of pieces of equipment would have intermediate values. See Ollinger et al, (2004) for a complete description of how the index was created and about the ERS survey.

Results

We ran separate regressions for the beef and hog carcasses, broilers, and ground beef products tested by FSIS. We used only year 2000 data because the ERS and one FSIS dataset contained data only from that year. The other FSIS datasets containing regulatory and performance information had multiple years. We had to combine year 2000 data with 2001 data for cattle slaughter because we only had 40 observations in the year 2000.

Tables 1-3 contain the parameter estimates for marginal effects of plant characteristics, food safety technology, regulatory effort and market mechanisms of food safety performance, i.e. the share of meat or poultry samples testing positive for *Salmonella.* All models were adjusted for multiplicative heteroskedasticity with the following specification: $\sigma_i^2 = \sigma^2 \exp(\gamma' Z)$ where Z is a vector of variables that affect the disturbance term, σ_i. In our case, Z = Log of OUTPUT and $\gamma = [\ln \sigma^2, \beta]$. A likelihood test shows that the heteroskedastic correction is significant for each model.

Regression results show that the joint likelihood of the model (equation 7) is significant in each case. Plant size is significant and positive in hog slaughter and ground beef and significant and negative for cattle slaughter. These differences are likely due to the range of food safety technologies available for different types of processing operations. Cattle slaughter plants have a variety of technologies that control pathogens either through heat or chemical solutions. These technologies become less costly per unit of output as plant size increases. Ground beef plants, on the other hand, have few food safety technologies other than sanitation and operating procedures to control pathogens. Since it is likely that smaller economies of scale occur in sanitation and operating procedures than in equipment, it may be that economies of scale enable large cattle slaughter to produce carcasses with lower pathogen counts than their smaller slaughter plant counterparts but such economies of scale do not exist in ground beef.

Results show that multi-species poultry and hog slaughter and ground beef plants are more likely to have meat or poultry samples test positive for *Salmonella*, perhaps because *Salmonella* grow readily and greater complexity makes food safety more difficult to control. Cattle slaughter plants that grind meat and ground beef plants that slaughter animals have a lower likelihood of having samples test positive for *Salmonella,* perhaps, because cattle slaughter plants with grinding operations take extra precautions to avoid pathogen contamination while poultry slaughter plants do not.

Why might cattle slaughter plants be more cautious about contaminating ground meat than poultry slaughter plants? Ground beef is used to make hamburgers and a wide range of other products that may be eaten without reaching the temperature needed to kill pathogens, making contaminated ground beef a potential source for severe gastrointestinal problems and a cause for numerous product recalls that have cost the industry millions of dollars. Ground poultry, on the other hand, is rarely eaten partially cooked and rarely recalled.

The other plant characteristic, whether the plant produces cooked products, was not significant. There were also other characteristics that we considered, including whether a cattle slaughter plant butchered cows and bulls, but they were not significant and were not included in our model.

Numerous food safety technology variables were examined, but only a few were significant or nearly significant. Even though cattle slaughter has a wide array of types of food safety equipment, none of them significantly affected positive *Salmonella* test results and only dehiding technology had much of an impact. Even within dehiding, only knife sanitation and, to a lesser extent, hand and glove sanitation (not shown) had a measurable impact on *Salmonella*. Poultry slaughter plants using an eviscerator that completely removes the viscera from the bird and hog slaughter plants employing steam vacuum machines to control pathogens after slaughter had fewer samples testing positive for *Salmonella*.

Food safety technology indexes were created for food safety equipment, testing, plant operations, dehiding (cattle slaughter only), sanitation, and overall (see data section for discussion). Only hog slaughter and ground beef plants with a food safety operating procedures index value in the 90th percentile had significantly fewer samples testing positive for *Salmonella*. The plant operations index includes responses to questions dealing with how the plant handles acceptable product that needs to be reworked, employees training, product refrigeration, and others. Results also show that a higher index value for dehiding technology reduced the number of samples testing positive for *Salmonella.* The dehiding index includes responses to questions dealing with knife and glove sanitation, whether air vacuums are used at the kill and hide removal station, etc.

Results show that equipment, testing, and sanitation technologies play little role in enhancing food safety and that plants must perform multiple operating tasks to benefit from improved food safety. Judging from these results, it appears that technology plays a small role in controlling *Salmonella.* Why might this be the case? It appears that plants are choosing food safety technologies that enable them reach their food safety goals. Plants that use fewer new technologies are likely the ones that need them the least and plants that use more have the greatest difficulty in controlling pathogens (Haavalar, Nauta, and Jansen). Thus, plants with a more technologically sophisticated facility likely have a greater need for the technology.

Poultry and hog plants often remove animals from feed prior to slaughter in order to reduce fecal matter. Results show that broiler plants removing animals from feed had fewer samples testing positive for *Salmonella* while hog plants had more samples testing positive.

The PR/HACCP rule contains three types of standards: process standards in which the regulating agency (FSIS) specifies tasks that must be performed to be in compliance, management based regulations (HACCP plans) that are established by the plant in consultation with the regulating agency (FSIS), and performance standards in which the regulating agency (FSIS) specifies a food safety performance target (a maximum number of samples testing positive for *Salmonella*). Regulators establish process standards and require management-based regulations in order to improve plant regulatory performance (reduce pathogens in plants). Thus, both the process and management-based regulations should reduce the number of samples testing positive for *Salmonella*.

Results show that as the share of HACCP tasks not in compliance with management plans rise, the number of samples testing positive for *Salmonella* also rises in each of the industries and significantly so in broilers and cattle slaughter. Tables 1-3 also show that the number of samples testing positive for *Salmonella* rises as the share of tasks not in compliance with SSOPs rises in ground beef and hog slaughter. A significant relationship exists in ground beef. The tables also show that a negative relationship exists between SSOPs and the number of samples testing positive for *Salmonella* in poultry and cattle slaughter. It appears that this is due to collinearity since the relationship becomes positive if the variable for HACCP noncompliance is removed. Overall, the results suggest that both process-based and management-based regulations improve food safety performance.

Notice the coefficients on the share of HACCP tasks not in compliance with regulations is larger than the coefficients on the share of SSOP task not in compliance in all cases, even ground beef. These findings suggest that the management-based regulatory approach (HACCP plans) have a greater impact on food safety performance than the regulator-based process standard (SSOPs). A 10 percent decrease in noncompliant HACCP tasks would reduce positive *Salmonella* test samples by about 5 percent in all industries except cattle slaughter, in which case the reduction would be about 3 percent. By contrast, the changes in noncompliant SSOP tasks varies from a decrease of about 4 percent in ground beef to an increase of about 1 percent in cattle slaughter.

Market mechanisms (customer specifications and export markets) negatively affect the share of samples testing positive for *Salmonella* in all industries except ground beef, which has a very small positive relationship. The relationship is significant and negative in broilers and cattle slaughter. The impact of market mechanisms in broilers is about a 6 percent reduction in positive *Salmonella* test samples and in cattle slaughter it is about 1 percent. For hog carcasses, there is about a 3 percent reduction. These results suggest that private markets play a vital role in reducing harmful pathogens in meat and poultry products.

Conclusion

This paper examined the impact of plant characteristics, food safety technology, two types of regulations, and market mechanisms on food safety performance, as measured by the number of product samples testing positive for *Salmonella* in an FSIS testing program. Plant characteristics – plant size, variety of species of animals slaughtered in the plant, and whether slaughter plants had grinding operations – had an important impact on *Salmonella* testing results. Specific food safety technologies, however, provided little advantage to their users. We attribute this finding to the incentives of firms to obtain more sophisticated technologies or employ more rigorous standards – both of which are costly. We suggest that plants with the most sophisticated technologies and techniques are the ones that most need them to avoid product contamination. Plants with less need for sophisticated technologies perform have no need to obtain them and so they do not.

The most important finding in the paper is the linkage between the PR/HACCP process standard (SSOPs) and the PR/HACCP managed regulatory approach (HACCP plans) to the PR/HACCP performance standard (*Salmonella* results). We found that both process and management-based regulations enhanced food safety performance. The more flexible management-based HACCP plans, which are developed by the plants and includes tasks that are monitored by FSIS, had the greatest impact in reducing *Salmonella* levels. We cannot say whether process or management-based regulations are superior because the two approaches covered different types of tasks that provide different opportunities for controlling pathogens. However, we can say that both regulations play an important role in controlling pathogens.

Another important result of this empirical research is the finding that market mechanisms reduce the likelihood of product contamination. This should not be too surprising. Large buyers, such as fast food restaurants, demand high food safety quality because they could lose their reputation for serving wholesome food if they serve food with low food safety quality. These and the other findings lead to overall conclusion that market mechanisms and flexible regulations have exerted powerful forces in improved pathogen control over meat and poultry.

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Table 1: Marginal Effects of Plant and Food Safety Technology, Customer Specifications, and Food Safety Effort on *Salmonella* Performance in Cattle Slaughter

	--------------------Cattle------------------		
Variable	Parameter Estimates	Parameter Estimates	Mean
CONSTANT	0.044** (0.023)	0.046* (0.024)	-
Log (POUNDS)	-0.0026** (0.0013)	-0.003** (0.0015)	16.56
MULTI-SPECIES	-0.0014 (0.005)	-0.004 (0.005)	0.77
GROUND	-0.013** (0.006)	-0.012** (0.006)	0.35
DEHIDE_TECH	-0.013** (0.0065)	-	0.444
DEHIDE_KNIFE	-	-0.005 (0.004)	0.525
HACCP_ NOCOMPLY	0.305** (0.099)	0.318*** (0.103	0.021
SSOP_NOCOMPLY	-0.109 (0.085)	-0.119 (0.092)	0.032
EXPORTS	-0.007 (0.005)	-0.010*** (0.005)	0.475
Observations	80	80	
X^2	27***	26***	

Table 2: Marginal Effects of Plant and Food Safety Technology, Customer Specifications, and Food Safety Effort on *Salmonella* Performance in Broilers and Hog Slaughter

	---------Broilers---------		-------------Hogs------------	
Variable	Parameter Estimates	Mean	Parameter Estimates	Mean
CONSTANT	0.243* (0.131)		-0.253** (0.110)	-
Log (POUNDS)	-0.001 (0.007)	18.22	0.014** (0.006)	16.00
MULTI-SPECIES	0.096*** (0.026)	0.233	0.082*** (0.029)	0.67
GROUND	0.110*** (0.030)	0.143	-0.006 (0.027)	0.62
COOKED	-0.029 (0.052)	0.039	-0.024 (0.026	0.59
EVISCERATOR	-0.037 (0.028)	0.169	-	-
STEAM_VAC	-	-	-0.106*** (0.039)	0.12
OPERATIONS_TEK_HI	0.015 (0.039)	-	-0.063* (0.034)	0.12
NOFEED	-0.161*** (0.039)	0.922	0.052* (0.029)	0.16
HACCP_NOCOMPLY	0.442** (0.215)	0.058	0.500 (0.570)	0.011
SSOP_NOCOMPLY	-0.055 (0.148)	0.097	0.178 (0.197)	0.045
CUSTOMER_SPECS	-0.063*** (0.022)	0.571	-0.028 (0.023)	0.33
Observations	77		82	
X^2	58***		22**	

Table 3: Marginal Effects of Plant and Food Safety Technology, Customer Specifications, and Food Safety Effort on *Salmonella* Performance in Ground Beef

Variable	Parameter Estimates	Mean
CONSTANT	-0.113** (0.050)	
Log (POUNDS)	0.007** (0.003)	15.67
MULTI-SPECIES	0.051** (0.025)	0.22
SLAUGHTER	-0.045** (0.020)	0.34
COOKED	0.004 (0.011)	0.57
OPERATIONS_TEK_HI	-0.039** (0.017)	0.13
HACCP_NOCOMPLY	0.538 (0.409)	0.007
SSOP_NOCOMPLY	0.374** (0.180)	0.024
CUSTOMER_SPECS	0.002 (0.011)	0.40
Observations	117	
X^2	22***	