United States
Department
of Agriculture

Economic
Research
Service

Economic
Research
Report
Number 75

July 2009

The Interplay of Regulation and Market Incentives in Providing Food Safety

Michael Ollinger
Danna Moore

www.ers.usda.gov

Visit Our Website To Learn More!

www.ers.usda.gov/Briefing/FoodSafety

National Agricultural Library Cataloging Record:

Ollinger, Michael

The interplay of regulation and market incentives in providing food safety.

(Economic research report (United States. Dept. of Agriculture. Economic Research Service) ; no. 75)

1. Animal industry—Law and legislation—United States.

2. Packing-houses—Sanitation—Economic aspects—United States.

3. Poultry plants—Sanitation—Economic aspects—United States.

I. Moore, Danna L. II. United States. Dept. of Agriculture. Economic Research Service.

HD9415

Photo credit: Shutterstock, Jelena Propic.

Recommended format for citation: Ollinger, M., and D. Moore. *The Interplay of Regulation and Market Incentives in Providing Food Safety,* Economic Research Report No. 75, U.S. Department of Agriculture, Economic Research Service, July 2009.

United States Department of Agriculture

Economic Research Report Number 75

July 2009

A Report from the Economic Research Service

www.ers.usda.gov

The Interplay of Regulation and Marketing Incentives in Providing Food Safety

Michael Ollinger, ollinger@ers.usda.gov

Danna Moore, moored@wsu.edu

Abstract

This report examines the impact of process regulations mandated under the Pathogen Reduction/Hazard Analysis and Critical Control Point (PR/HACCP) rule by the Food Safety and Inspection Service of USDA on food safety process control. The current level of food safety found in U.S. meat and poultry food products is a result of process and performance regulations and management-determined actions brought about by market incentives. Processing regulations include sanitation and other tasks related to food safety; management-determined actions include capital investment and other actions independent of process regulations, but possibly driven by performance standards. Performance standards—regulations that allow manufacturers to reach an acceptable level of food safety in any manner they see fit—are not a subject of this report. This study used the share of samples testing positive for *Salmonella* spp. as a measure of food safety process control in meat and poultry processing plants and found empirically that management-determined actions account for about two-thirds of the reduction in samples testing positive for *Salmonella* spp., while process regulations account for about a third of the reduction. The importance of process regulation varies, but accounts for 50 percent or more of process control in about a quarter of plants, and in some plants accounts for the entire process control system.

Keywords: food safety, process regulations, Hazard Analysis and Critical Control Point (HACCP) rule, food safety regulations

Acknowledgments: The authors appreciate the reviews and suggestions of Elise Golan, Jay Variyam, and Laurian Unnevehr (Economic Research Service); Neil Hooker (Ohio State University); and Sang Nyugen and Arnold Reznek (Center for Economic Studies, U.S. Census Bureau).

Contents

Summary

The current level of food safety found in U.S. meat and poultry products is a result of both Government regulations and management-determined actions motivated by market incentives. For meat and poultry processing plants, the U.S. Government mandates both food safety process regulations that require specific technologies or production practices and performance regulations that promulgate acceptable levels of food product safety. Meat and poultry processing plants are also influenced by market incentives, including legal liability, the value of their brand, and their desire to sell more of their food product. Companies often negotiate contracts, which, in exchange for higher prices or guaranteed purchases, specify food safety levels to be achieved or technologies to be used.

What Is the Issue?

The Food Safety and Inspection Service (FSIS) recently made changes to its regulatory policies to better align its program with current food safety needs. FSIS faces pressure, however, to do more to protect the public in the area of food safety. The Economic Research Service (ERS) estimates society's costs (which includes medical costs, lost labor, etc.) of just *Escherichia coli* STEC and Guillain-Barré syndrome at about $1.6 billion per year. The cost of foodborne illness from other sources, such as *Salmonella* species (spp.), is much higher.

Current levels of food safety process control are achieved through a combination of Government regulations (process and performance standards) and private management-determined actions, but little is known about the relative contributions of each to food safety process control. This report helps fill that knowledge void by examining the impact of food safety process regulations and management-determined actions as measured by the share of samples testing positive for *Salmonella* spp. in a testing program conducted by FSIS. The findings provide lessons for the development of new regulatory approaches to food safety process control.

What Did the Study Find?

This study's examination of the effects of mandatory process regulations and management-determined actions on *Salmonella* spp. provides new information on the role of regulations and market incentives in ensuring food safety process control. The study found that management-determined actions accounted for about two-thirds of the reduction in the number of samples testing positive for *Salmonella* spp. (*Salmonella* share)—a measure of food safety process control. By contrast, process regulations accounted for about a third of the reduction of samples testing positive. The importance of process regulation varied across plants, accounting for more than half of all food safety process control for about a quarter of the plants and for the entire food safety process control system of some plants. These results suggest that both process regulation and management-determined actions play vital roles in meat and poultry food safety process control.

Mandatory process regulations include cleaning and sanitation tasks and tasks required to implement a Hazard Analysis and Critical Control Point

(HACCP) plan for pathogen reduction (PR). Management-determined actions include investments in human and physical capital, food safety technologies, and organizational arrangements, such as contractual relationships that enhance food safety process control. These management-determined actions are driven by market forces and federally mandated performance standards that establish limits on pathogens, but do not specify a way to reach those limits.

The study also found that nearly half of all *Salmonella* spp. reduction due to management-determined actions was motivated by direct contractual relations in which a major customer of a meat or poultry plant or supplier to a meat or poultry plant, fearing a loss of public confidence in the safety of its products, agreed to pay a price premium, make minimum purchases, or offer other inducements to suppliers in exchange for greater attentiveness to food safety process control. Management-determined actions were also motivated by indirect consumer pressure for food safety; consumers link contaminated food products to a supplier through branded products and other sources and can, in turn, cease purchases if products fail to meet their expectations for food safety.

The forces driving management-determined actions lead to the conclusion that USDA's FSIS could increase incentives by providing consumers and buyers with more information about the meat and poultry food safety control of particular plants and firms. USDA's FSIS records plant performance on *Salmonella* spp. tests and noncompliance with process regulations. Making this information public should encourage greater food safety investments by meat and poultry producers.

How Was the Study Conducted?

Food safety control is measured as the number of samples testing positive for *Salmonella* spp. as a percentage of all samples taken by FSIS for each round (sample set) in a *Salmonella* spp. testing program for four major products: broiler (young chicken) carcasses, cattle (cow/bull and steer/heifer) carcasses, market hog carcasses, and ground beef. These pathogen test results are linked with other datasets from FSIS and from the Economic Research Service (ERS). FSIS data provide measures of plant-level performance for mandated sanitation and HACCP tasks, and another dataset offers plant characteristics, such as the value of sales, number of employees, etc. The ERS data include information on plant-level food safety processing technologies, such as steam vacuum units, contractual arrangements with buyers and sellers, and some plant characteristics. Since the ERS dataset covers only information from the year 2000, the analysis was limited to that timeframe.

The analysis used a Tobit regression to evaluate the impact of process regulations and management-determined actions on shares of samples testing positive for *Salmonella* spp. After finding the marginal effects, an estimate was made of the change in *Salmonella* shares due to 20-percent changes in the variables representing process regulations and management-determined actions. The share of changes attributed to process regulations and management-determined actions were then computed.

Introduction

The interplay of regulation and market incentives in food safety control is not well understood. Yet, this information is vital for the efficient design of food safety regulations. The characteristics of efficient regulation differ depending on the level and extent of food safety provided by market incentives. If market incentives are strong, then regulation may be structured to strengthen those incentives. If market incentives are weak, however, task-oriented process requirements may be necessary.

Current food safety regulations for meat and poultry include process requirements that mandate specific technologies or production practices and performance requirements that specify final product quality. Process regulations are practices that experts believe lead to greater food safety in food processing. These practices include the cleaning and sanitation tasks that the Food Safety and Inspection Service (FSIS) has required for many years and the monitoring tasks of critical plant operations that are included in a plant's Hazard Analysis and Critical Control Point (HACCP) plan. These process regulations do not specify a level of food safety. By contrast, food safety performance standards specify a level of food safety, but allow producers to reach that level any way they choose. The Pathogen Reduction/HACCP rule mandates performance standards for two pathogens: *Salmonella* spp. and generic *E. coli*.

Market incentives include general liability for food safety, brand-value concerns, and opportunities to enter into private contracts that specify food safety levels or technologies in exchange for market access or higher payments. Market incentives and performance standards drive management-determined actions. Management-determined actions are defined as any food safety initiatives undertaken by meat or poultry suppliers that are not mandated under Government process regulation. These actions include investments in human and physical capital, food safety processing technologies, Government performance standards, and organizational arrangements, such as contracts between buyers and processing companies.

Few studies address the impact of meat and poultry food safety regulation on pathogen levels. In the most recent report that directly examined pathogen levels, FSIS (2005) measured the share of red meat and broilers that tested positive for *Salmonella* spp. (the number of samples testing positive from all plants tested divided by all samples taken). The study found that the share of market hog carcasses testing positive for *Salmonella* spp. declined between 2000 and 2001 and then held steady through 2005. The share dropped in cow/bull carcasses during 2001-05. From 2000 to 2005, the share trended down in ground beef, held steady in steer/heifer carcasses, and increased in broilers (table 1).[1] *Salmonella* shares in ground chicken have also risen since 2000, although that observation is based on fewer samples. FSIS (2005) attributes changes in *Salmonella* shares over 2000-05 to the PR/HACCP rule and private efforts, such as capital investments, by companies. FSIS also notes that it is not statistically valid to compare the share of total samples that test positive for *Salmonella* spp. over time because external factors, such as weather, season, and location, affect *Salmonella* shares.

[1] Some *Salmonella* serotypes are not human pathogens. *Campylobacter* spp. is another commonly occurring pathogen in pork and poultry and has been the subject of mitigation efforts by FSIS.

Table 1
The prevalence of *Salmonella* spp. in red meat products and broilers, 2000-2005

Year	Broilers	Market hog carcasses	Cow/bull carcasses	Steer/heifer carcasses	Ground beef	Ground chicken	Ground turkey
Sample sets tested for *Salmonella* spp.				*Number*			
2000	190	66	32	11	446	5	17
2001	170	97	34	13	426	6	16
2002	186	159	68	42	632	8	18
2003	127	109	45	40	547	4	16
2004	144	130	61	72	571	5	21
2005	171	113	38	24	391	5	13
Samples testing positive for *Salmonella* spp.[1]	Broilers	Market hog carcasses	Cow/bull carcasses	Steer/heifer carcasses	Ground beef	Ground Chicken	Ground turkey
2000	9.1	6.2	2.2	0.4	3.3	13.8	25.7
2001	11.9	3.8	2.4	0.6	2.8	19.5	26.2
2002	11.5	3.2	1.7	0.3	2.6	29.1	17.9
2003	12.8	2.5	1.5	0.4	1.7	35.5	25.4
2004	13.5	3.1	0.8	0.3	1.6	25.5	19.9
2005	16.3	3.7	1.3	0.6	1.1	32.4	23.2
Baseline samples testing positive for *Salmonella* spp.[2]	Broilers	Market hog carcasses	Cow/bull carcasses	Steer/heifer carcasses	Ground beef	Ground chicken	Ground turkey
Pre-1996	20.0	8.7	2.7	1.0	7.5	44.6	49.9

[1] A test sample is the unit tested for *Salmonella* spp. A group of samples comprise a set. The number of samples per set varies by product category. FSIS determines the baseline number of samples permitted to test positive for *Salmonella* spp. and the number of samples needed for each set.

[2] The baseline estimate is the pathogen level present in samples taken prior to promulgation of the PR/HACCP rule of 1996.

Source: U.S. Department of Agriculture, Food Safety and Inspection Service, *Progress Report on Salmonella spp. Testing of Raw Meat and Poultry Products, 1998-2005* and *Progress Report on Salmonella Testing of Raw Meat and Poultry Products, 1998-2003*, www.FSIS.USDA.gov/science/progress_report_salmonella_testing_1998-2004/index.

The FSIS findings show changes in *Salmonella* spp. over time, but do not empirically sort out the contributions that process regulations and management-determined actions have made to reducing contamination. The purpose of this report is to evaluate, for meat and poultry processing plants, the impact of food safety process regulations and management-determined actions on the prevalence of *Salmonella* spp. in four products: cattle and hog carcasses, ground beef, and broilers. We hypothesize that economic forces drive management-determined actions and compel managers to adopt different levels of food safety process controls. Plant managers with strong market incentives take many management-determined actions, resulting in levels of food safety process control that exceed those mandated under the PR/HACCP rule. Plant managers who face minimal market incentives may take no management-determined actions, leading to levels of food safety process control that just meet the mandated level. Results are consistent with this hypothesis.

Our analysis uses simple statistics and a Tobit regression to estimate the marginal effects of process regulations and management-determined actions, and then computes how *Salmonella* spp. reduction can be attributed to each. The availability of four unique datasets was crucial to the analysis:

- Economic Research Service (ERS, USDA) dataset of plant characteristics and meat and poultry food safety technology.
- FSIS dataset of *Salmonella* spp. test results for animal carcasses and ground meats.
- FSIS dataset on the performance of tasks required by regulation.
- FSIS dataset of plant-level meat or poultry sample-testing results for *Salmonella* spp.

Previous Regulatory Standards and the 1996 PR/HACCP Rule Form the Basis for Current Food Safety Regulation

FSIS and its antecedent agencies have regulated meat and poultry food safety process control systems since Congress mandated in 1906 that plants follow hygienic meat processing practices. Congress greatly expanded this authority under the Wholesome Meat Act (WMA) and the Wholesome Poultry Products Act (WPPA) of 1967 and 1968. Among other provisions, the WMA, WPPA, and the subsequent regulations established Standard Sanitation Operating Procedures (SSOPs) and facility control tasks (FCs) that required plants to perform a number of tasks related to 15 sanitation and process control practices.[2] The SSOPs included sanitation tasks, such as cleaning and sanitizing assembled and disassembled equipment, while facility control requirements dealt with activities that could cause contamination of finished products, such as raw meat coming into contact with cooked products and the presence of rodents. FSIS also promulgated regulations dealing with cooking times and temperatures, preparation of fermented, smoked, and other processed products, and other matters that increase the risk of foodborne illness associated with meat and poultry. (See Ollinger and Mueller (2003) for further discussion.)

[2] The term SSOP (standard sanitation operating procedures) did not come about until much later. We use it in this report to refer to sanitation practices mandated under the WMA and WPPA and its subsequent regulations and other sanitation practices required under PR/HACCP.

FSIS expanded its regulatory authority when it put forth the final PR/HACCP rule on July 25, 1996. The Agency completely phased in the regulation by January 31, 2000. Among other provisions, the rule required plant managers to:

- Develop and implement HACCP process control programs for each product under the guidance of FSIS.
- Incorporate SSOPs, FCs, and HACCP plans into its HACCP program.
- Accept responsibility for meat and poultry food safety process control.

HACCP Programs, SSOPs, and FCs as Process Regulations

HACCP programs include a plan that outlines criteria to ensure food safety process control and associated mandated tasks. There are two key features of the HACCP plan:

1. Plant managers specify their own HACCP plans and accompanying tasks.
2. Tasks are intended to spot deviations from normal operating conditions, but are not ends in themselves. If deviations from the standard are detected, plant managers must bring their food safety process control systems in line, using whatever means they deem necessary.

SSOPs and FCs, on the other hand, include specific tasks that meet regulatory process standards. If plants complete their prescribed tasks, then their obligation ends.

FSIS inspectors monitor HACCP, SSOPs, and FCs to ensure compliance. If a task has not been performed, then an FSIS inspector files a noncompliance report. Chronic failure to comply can lead to penalties. Maintenance of the HACCP, SSOP, and FC tasks require labor but no capital investments, although plant managers may incur maintenance costs to bring a food safety process control system under control.

SSOPs and FCs are considered process regulations because they are food safety tasks (technologies) required by regulators. HACCP plans are called management-based regulations by Coglianese and Lazar (2002), but we define them as process regulations because they are mandated monitoring systems that must meet specific FSIS criteria, are checked by FSIS to ensure compliance, and do not specify a level of food safety product performance (i.e., they mandate no maximum allowed threshold of harmful pathogens).[3]

FSIS Establishes *Salmonella* spp. Testing as an Indicator of HACCP System Performance

PR/HACCP also requires slaughter plants to test for generic *E. coli* and comply with the industry standard. Additionally, PR/HACCP mandates that slaughter plants and ground meat and ground poultry plants comply with a *Salmonella* standard. That standard requires that plants have no more than a maximum number of samples that test positive for *Salmonella* spp. out of a larger number of samples taken by FSIS inspectors in an FSIS testing program. Economists consider the generic *E. coli* and *Salmonella* spp. standards performance standards. These standards do not prescribe any type of process control technology. Rather, high levels of the test organism indicate a poorly performing meat or poultry food safety process control system and can be used as a reason to declare a product adulterated.

FSIS verifies compliance with the generic *E. coli* and *Salmonella* spp. performance standards with specific testing requirements. FSIS established pathogen target prevalence in broilers, steers/heifers, cows/bulls, and market hog carcasses for both generic *E. coli* and *Salmonella* spp. and in ground beef, chicken, and turkey for *Salmonella* spp. FSIS verifies compliance with the *Salmonella* spp. standard using its own tests and requires plant managers to conduct their own generic *E. coli* tests. For more information about generic *E. coli* testing, see Ollinger and Mueller (2003).

Robert Umholtz (personal communication on June 21, 2000) described FSIS's procedures for the *Salmonella* spp. testing program as follows:[4]

1. FSIS randomly selects plants from a pool of plants that are not undergoing testing.[5]

2. FSIS evaluates a set of samples for *Salmonella* spp. over a test period that can last several days, weeks, or months, depending on the frequency of production runs.

3. Plants that exceed the maximum allowed number of positive *Salmonella* spp. samples in the first sample set ("A" set), of at least 50 samples (the number varies by product category), must alter their meat

[3] Some features of HACCP programs differ from traditional process standards in that plants construct their own HACCP plans and choose the tasks required under it. However, once this HACCP plan is selected and the tasks outlined, it becomes the mandated technology and FSIS inspectors verify compliance, as they would with SSOPs or any other process task. Also, regulation 9 CFR 417.2(c)(3) requires that an establishment's HACCP plan meet critical limits and regulatory requirements, including mandatory pathogen reduction standards.

[4] As of January 2, 2009, FSIS was in the process of changing how it selects plants for testing.

[5] FSIS now uses a risk-based approach to select plants for testing.

and poultry food safety process controls and then submit to a second round of testing (“B” set).

4. If the plant fails again, it must make further changes to its processing system and undergo further testing (“C” set).

5. Failure to pass another attempt (“D” set) can be a contributing factor to the suspension of inspection services and the resulting plant closure. The suspension remains in effect until the plant provides more effective process controls.[6]

Plants have rarely failed *Salmonella* spp. compliance testing. Umholtz (June 2000) said that only about 100 of the approximately 2,050 slaughter and grinding plants tested through 1999 failed to pass the first test (“A”) and only 22 of those 100 plants failed their first two tests (“A” and “B”). Of the 22 plants, 19 passed the third test (“C”) and only one failed all three (Supreme Beef) and eventually was forced to exit the industry. The other two plants eventually resumed production.

FSIS is changing its *Salmonella* control program to The *Salmonella* Initiative Program (SIP), which scores plants based on previous pathogen tests and categorizes them as category 1 (performs at 50 percent below baseline level), category 2 (passes, but at more than 50 percent baseline level), and category 3 (performs at higher level than baseline level). SIP is described in greater detail at http://www.fsis.usda.gov/Science/*Salmonella*_Verification_Testing_Program/index.asp and http://www.fsis.usda.gov/pdf/scheduling_criteria_*Salmonella*_sets.pdf. SIP is intended to encourage higher food safety performance by publishing all plants ranked as category 2 and 3. Plants identified as category 2 and 3 performed the most poorly on *Salmonella* testing. Plants in category 2 are identified at http://www.fsis.usda.gov/PDF/Category_2_Broilers.pdf and those in category 3 are at http://www.fsis.usda.gov/PDF/Category_3_Broilers.pdf.

[6] All meat and poultry processing plants that ship meat and poultry products in interstate commerce must be inspected by FSIS. Suspension of inspection service means that plants cannot ship products across State lines.

Management-Determined Actions and *Salmonella* spp. Performance Standards

Performance standards differ from process standards in that plant managers can take whatever actions they deem necessary to meet a performance standard. For example, one plant may use heat treating equipment, another may adopt a novel approach to personnel management, and another may install new ventilation systems as ways to get a system in compliance with a regulatory standard. While this type of regulation does provide flexibility, it also carries risks. Plant managers must determine the technologies required for compliance, suggesting that some level of experimentation and risk-taking is necessary.

Plant managers can take management-determined actions to correct a recent performance test failure (corrective actions) or to avoid future scrutiny (preventive actions). Incentives for taking corrective actions are strong since plant managers could face penalties for failure to regain process control. Incentives for taking preventive actions are weaker since there is no immediate pressure. Penalties for failure to meet performance standards include extensive management time, regulatory sanctions (shutting down operations), fines, line stoppages, retesting, and lost sales due to adverse buyer reactions (reputation costs).

PR/HACCP performance standards have had weak penalties associated with them. Until recently, FSIS did not publicize *Salmonella* spp. test results, so reputation costs were lower than if publicized.[7] Moreover, a ruling in a case involving Supreme Beef Company limited FSIS authority to impose penalties on plants failing to meet *Salmonella* spp. performance standards. Nevertheless, there are line stoppages, management attention, and other relevant costs.

Other Pathogen Control Programs

Aside from the PR/HACCP rule, FSIS prohibits detectable levels of *E. coli* O157:H7 and *Listeria monocytogenes*, two human pathogens, and excessive levels of *Salmonella* spp. in meat and poultry products.[8] FSIS monitors compliance with *E. coli* O157:H7, *Listeria monocytogenes*, and *Salmonella* spp. limits and will recall products if necessary.[9] Common reasons for recalls include linking products to illnesses by the Centers for Disease Control and Prevention (CDC) and State testing programs or by the companies themselves. Publicity about foodborne illness outbreaks and food supply safety has led to a network of monitoring programs by FSIS, CDC, State health agencies, and other organizations to ensure that the discovery of contaminated meat or poultry is followed by a public announcement and a recall of meat or poultry products.

[7] FSIS strengthened enforcement of the standard by posting *Salmonella* categories for individual plants, starting with broilers in 2008.

[8] According to an anonymous FSIS official, regulations require 6.5 and 7-$\log_{10}$ reductions in *Salmonella* in certain ready-to-eat meat and poultry products, respectively, but any amount renders them adulterated.

[9] FSIS has a risk-based verification sampling program for *Listeria monocytogenes* that targets inspections at establishments producing ready-to-eat meat and poultry products that support the growth of *Listeria monocytogenes.* The response to *Listeria monocytogenes* or *Salmonella* spp. depends on whether or not the product is ready-to-eat.

Economic Incentives for Maintaining Food Safety

The costs to firms and society of imprecise meat and poultry food safety monitoring first became apparent in the 1980s and 1990s when *E. coli* O157:H7 in hamburgers at McDonald's, Jack-in-the-Box, and other restaurants caused outbreaks of foodborne illnesses that resulted in several deaths, production plant closures, and near bankruptcies at other processors. The television show 60 *Minutes* highlighted the risks of *Salmonella* spp. contamination in chicken, while the CDC and FSIS expanded and improved product testing (Ollinger and Mueller, 2003). Fearing lost sales, managers of chicken slaughter plants developed and installed counter-current scalders, bird washes, chlorine rinses, and other pathogen-reducing technologies (Waldroup et al., 1992). Other manufacturers sought new meat and poultry food safety control technologies, such as those described in Ollinger, Moore, and Chandran (2004).

The concern for meat and poultry food safety, fear of reputation loss for selling unsafe food, and the search for greater profitability led to changes in the marketplace. Large restaurants, grocery chains, and other buyers that purchase huge amounts of meat and poultry demanded stricter meat and poultry food safety standards from their suppliers and, in return, granted lucrative single-source contracts (Ollinger and Mueller, 2003; Golan et al., 2004). Moreover, a shift to the production of branded products provided consumers with a clear association between producers and their products, giving producers a stronger incentive to ensure meat and poultry food safety (Ollinger and Mueller, 2003).

Economists have examined the effects of reputation loss due to producing unsafe food. Thomsen and McKenzie (2001) found that firms that voluntarily recalled contaminated meat and poultry products suffered a decline in longrun profitability (i.e., significant declines in stock prices). Additionally, Ollinger and Mueller (2003) report anecdotal evidence indicating that plants suffering recalls incurred higher liability and process control costs. A number of studies (Piggott and Marsh, 2004; Marsh, Schroeder, and Mintert, 2004) determined that adverse meat and poultry food safety events led to temporary declines in meat and poultry consumption. Thomsen, Shiptsova, and Hamm (2006) established that sales of branded frankfurter products declined more than 20 percent after a product recall. Hudson Meats suffered a massive recall in 1998 and eventually exited the industry.

Adverse media publicity, fear of reputation loss, and demand from customers for safer products put pressure on meat and poultry firms to take their own actions. At the same time, FSIS mandated new performance standards (*Salmonella* spp. and generic *E. coli* performance criteria) that require no specific technology, giving plant managers the option to take any action necessary to meet the standards. Finally, FSIS promulgated more stringent meat and poultry food safety process regulations (SSOPs and HACCP tasks).

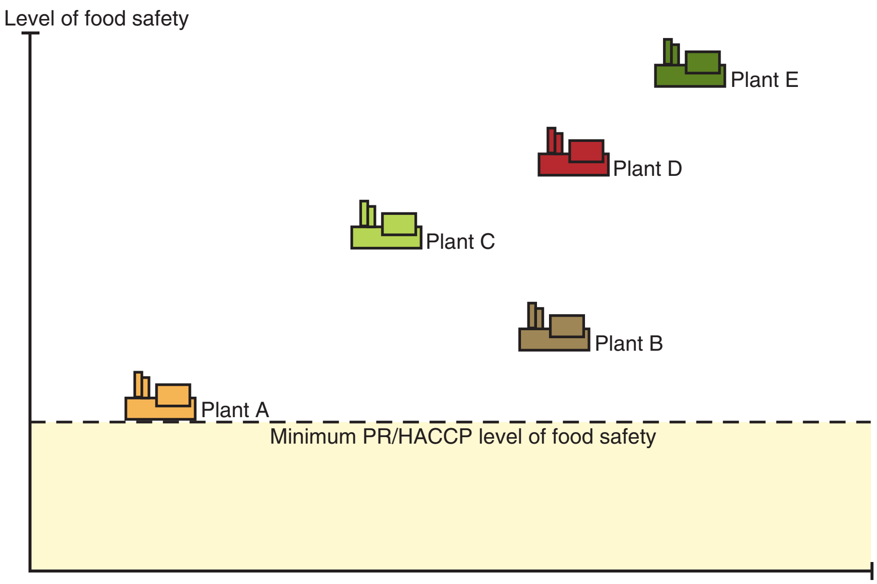
Private and Public Incentives Lead to Different Levels of Food Safety Process Control

A fundamental belief among economists is that firms want to maximize their profits. In terms of food safety, this means that plant managers undertake investments only up to the point at which it is no longer profitable for them to do so. Plants facing market pressures for food safety from several sources would likely make substantial investments in food safety process control, whereas a plant facing minimal pressure may make no such investments (fig. 1).

The buildings in figure 1 are hypothetical points representing plants with different levels of food safety process control. Plant A chooses the minimal level of food safety process control allowed by the PR/HACCP rule. Two other plants—plants B and C—choose levels that are slightly more stringent than those dictated under the PR/HACCP rule, while plants D and E select levels of food safety process control much greater than that demanded under PR/HACCP.

The levels of food safety process control shown in figure 1 vary because plants face different market demands. Plant A takes no management-determined actions and has a relatively low level of food safety process control. Plants like this may be willing to invest only to the level of food safety process control required under PR/HACCP because they sell generic products that are commingled with other products. These plants face very little pressure to provide food safety because it is difficult for buyers to link these plants to their products, eliminating potential liability for the sale of contami-

Figure 1
Hypothetical mean level of food safety under the 1996 PR/HACCP rule



Source: Economic Research Service calculations.

nated products. Other plants face various levels of demand for food safety process control from their markets. Plants B and C may sell branded products and may be identified in the event of a foodborne illness outbreak. Plants D and E may face even more pressures. For example, they may sell brand-name products, operate as single sellers in some markets or to some retail outlets, and face buyer requirements from a major fast food restaurant and, thus, be closely linked to its products and be held liable for any contamination.

Economic Framework

Plants achieve a level of food safety process control through their own management-determined actions and compliance with mandated process regulations. Management-determined actions are manifested in inputs of labor, human and physical capital, and technology and can be either direct or indirect.[10]

Direct actions include:

1. Meat and poultry food safety processing technologies, such as carcass pasteurizers and chlorinated water baths.
2. Organizational arrangements, including contractual agreements with buyers and sellers.

Indirect actions include:

1. A plant's own production technology (e.g., plant size).
2. Other factors beyond the control of plant managers that affect food safety, such as seasonality or the cleanliness and condition of the animal at the time of slaughter.

We examine the impact of management-determined actions and process regulations on food safety with a reduced-form production function. This model has no specified functional form, but does provide a framework in which inputs of labor, capital, and food safety technologies are combined to produce food safety. Refer to appendix A for a complete discussion of this model.

Human and Physical Capital Investments Limit the Spread of Pathogens

Human capital includes general actions, such as hiring more workers devoted to meat and poultry food safety process control, targeting investments to worker training, or empowering workers to take greater responsibility for meat and poultry food safety process controls. Hatfield Meats provides an example of a targeted investment. This company set up a program in which production workers further up the processing line alert downstream workers when process control failures arise so downstream workers can make corrective adjustments (Bolton et al., 1999).

Physical capital investments are expenditures on the plant and specialized processing equipment designed to control pathogens. Plant investments, such as modifying ventilation systems or improving drainage, are ways to reduce the threat of food contamination by eliminating or controlling sources of pathogens. For example, Sara Lee invested millions of dollars in its ventilation systems and other plant facilities after it discovered that those systems were sources of pathogen contamination (Kenneth B. Moll & Associates, January 1999).

Plant managers can also change plant layouts to alter product flows and eliminate critical points that may be prone to cross-contamination. For example,

[10] Human and physical capital investments are generally management-determined actions because Government regulations do not mandate these investments. Investment is required for validating HACCP plans, but that type of investment is not included here.

some plant managers choose to redesign their plant layout to prevent raw meat from coming in contact with finished products.

Processing Technologies Control Pathogens

Plant managers have developed innovative sanitation and operating procedures, product and environmental pathogen testing approaches, and equipment and processing techniques that kill, control, or detect pathogens. Advanced hide-removal equipment, for example, limits contamination by peeling away the hide so it does not touch the exposed meat. Additionally, steam vacuum units, which heat carcass exteriors, and other heat-treating equipment and chemical control devices, such as chlorine baths, kill pathogens outright. Also, more intensive cleaning can prevent pathogens from ever establishing themselves. See Ollinger, Moore, and Chandran (2004) and Roberts (2005) for examples of other technologies.

Organizational Arrangements Facilitate Food Safety Process Control

Organizational arrangements—vertical and horizontal management relationships within the firm and contractual relations with buyers and suppliers outside the firm—are other ways to control pathogens. Williamson (1985) argues that spot market purchases—transactions with minimal contact between a buyer and producer—are the simplest type of contract. These purchases, however, require that quality be obvious to the buyer because suppliers lose the incentive to provide adequate product quality if they cannot be held accountable for hidden flaws.

Williamson (1985) suggests that firms enter into contractual arrangements when product quality cannot be easily evaluated and the potential costs of purchasing low-quality products are high. For meat and poultry plants, failure to detect contamination in meat and poultry, in addition to being very costly, can become a source of unwanted negative publicity. One major outbreak at a Jack-in-the-Box restaurant in the early 1990s cost three people their lives, prompting Jack-in-the-Box and other large meat and poultry buyers in the United States to demand more sophisticated meat and poultry food safety process control systems from suppliers (Ollinger and Mueller, 2003; Golan et al., 2004). Today, most large restaurant chains, grocery stores, and other large buyers enter into highly detailed contracts with suppliers in which buyers make large-volume purchases and suppliers use the food safety practices and technologies demanded by the buyer. Buyers benefit from reduced business risks, and sellers benefit from higher prices or guaranteed markets (Ollinger and Mueller, 2003; Golan et al., 2004). Henson and Northern (1998) and Balsevich et al. (2003) identify similar cases in the United Kingdom and Latin America. Starbird (2005) notes that contracts reinforce product food safety, since sellers must adhere to quality standards.

Other marketing methods may also encourage investments in meat and poultry food safety process controls. Klein and Leffler (1981) argue that producers of branded products must support their brands by investing in quality control. To our knowledge, however, there is no empirical evidence either supporting or refuting their argument in the case of meat and poultry food safety.

Some evidence shows that export markets impose food safety process control requirements. For example, Japanese and South Korean buyers imposed controls on U.S. suppliers due to concerns over bovine spongiform encephalopathy (BSE) or “mad cow” disease. Additionally, economists (Henson, Brouder, and Mitullah, 2000; Jaffee and Masakure, 2005) report that Kenyan fish and vegetable exporters had to comply with European Union standards before they gained access to the European market.

Sometimes contractual arrangements become burdensome, but production processes are compatible enough within a plant that managers choose to vertically integrate. Williamson (1985) and Reimer (2006) argue that vertical integration offers greater control over product quality because one management controls the entire process, thereby eliminating the need for contractual negotiations.

Ground meat and poultry producers may be more susceptible to selling contaminated meat because they rely on the food safety quality of inputs supplied to them by outside firms.[11] In a vertically integrated operation, the manager of a ground meat plant knows the conditions under which their meat or poultry inputs were produced and can control that quality through lines of authority within the plant. Vertical integration should be more likely between slaughter plants and ground meat facilities or final processors than between slaughter plants and growers or retailers, because ground meat production is a production process and easily integrated into a slaughter plant, whereas animal husbandry and retailing are not.

[11] As pointed out by an anonymous reviewer, it has not been proven that ground meat producers with multiple suppliers are more likely to sell contaminated meat. It depends on the food safety process controls of the supplier (i.e., a plant with one supplier with weak controls may be more susceptible to contamination than a producer with several suppliers using strong controls). Nevertheless, if all suppliers are equal, the probability of producing contaminated products does rise with the number of suppliers.

Plant Size and More Complex Operations Affect Food Safety Process Control

Plant size and other elements of basic plant technology indirectly affect meat and poultry food safety process control. Williamson (1985) argues that plant size drives economies of scale in production, but yields diseconomies of scale in bureaucracy. Economies of scale in production means that larger plants can spread the cost of a microbiological laboratory and other food safety technologies over a much larger volume of output, resulting in a lower fixed cost per unit relative to smaller plants. Large plants, however, may also have higher bureaucratic costs due to added controls that ensure smooth information flow over longer and more complex lines of control and the need to rapidly process information about a broader mix of inputs and outputs. Increased bureaucracy might mean slower responses to food safety process control failures and greater reporting and management costs.

Different animal species may also inherently harbor certain pathogens. For example, *E. coli* O157: H7 occurs in cattle but not in poultry, whereas *Salmonella* spp. is more prevalent in poultry and hogs. These pathogens may require different process control methods and record-keeping techniques, raising the cost of food safety process controls. Food safety experts also indicate that pathogen prevalence may vary within species (e.g., cows and bulls versus steers and heifers) and by season and region of the country.

Empirical Measures Link Food Safety to Management-Determined Actions and Process Regulations

We have sketched out a food safety production function in which inputs of labor, capital, and food safety technologies are combined to produce food safety (i.e., control pathogens). The food safety variable should be the actual level of pathogens in the meat or poultry produced by the plant. This level may or may not exceed the tolerance level (i.e., the level of pathogens that is safe for human consumption) and is strictly regulated by FSIS. The inputs (independent variables) are manifested in management-determined actions and process regulations.

Data on *Salmonella* spp. shares from FSIS's testing program served as our measure of food safety. In this program, FSIS permits a maximum number of samples to test positive for *Salmonella* spp. out of a certain number of samples taken. For example, for a plant to pass inspection, FSIS might require that no more than 2 samples out of 50 samples taken from hog carcasses test positive for *Salmonella* spp. We define our measure of food safety—*Salmonella* share—as the number of meat or poultry samples taken by FSIS that test positive for *Salmonella* spp. divided by the total number of

Table 2
Plants with *Salmonella* shares, by product category, 2000[1]

Salmonella shares	Product categories				
	Cattle carcasses	Ground beef	Hog carcasses	Broilers	Mean
			Share of plants		
0	53.6	43.2	46.1	12.2	38.8
0-2	20.2	20.2	8.4	13.3	15.5
3-5	13.1	13.3	13.5	16.0	14.0
6-10	10.7	16.3	15.2	23.4	16.4
11-20	1.2	5.6	9.0	20.2	9.0
21-30	1.2	0.9	5.0	9.0	4.0
Greater than 30	0	0.5	2.8	5.9	2.3
Total	100	100	100	100	100
	Test sets				
	Cattle carcasses	Ground beef	Hog carcasses	Broilers	Mean
			Number of plants		
0	45	354	82	23	126.0
0-2	17	166	15	25	56.0
3-5	11	109	24	30	43.5
6-10	9	134	27	44	53.5
11-20	1	46	16	38	25.2
21-30	1	7	9	17	8.5
Greater than 30	0	4	5	11	5.0
Total[2]	84	820[3]	178	188	-

[1] FSIS tests 50 or more samples in sequence for *Salmonella* spp. from each plant that produces cattle or hog carcasses, ground meat or poultry, or broilers. *Salmonella* shares equal the number of samples testing positive for *Salmonella* spp. divided by the number of samples in the test set. A test set is the total number of samples FSIS takes each time a plant undergoes testing. If a plant has enough positives to fail a test or enough negatives to pass a test, FSIS stops sampling.

[2] Total number of plants undergoing testing for *Salmonella* spp. in 2000.

[3] Includes many nonmanufacturing plants, such as retailers and wholesalers.

Source: Economic Research Service estimates based on FSIS *Salmonella* spp. testing data.

samples.[12] The hypothetical range of the *Salmonella* share includes zero, one, and all values in between. In practice, many plants had some positive samples but no plant had only positive ones, making the distribution bounded from below but not from above (table 2).

Table 3 shows how *Salmonella* share (top panel), plant size (middle panel), and the total number of plants (bottom panel) vary with management-determined actions in cattle and hog carcass, ground beef, and broiler plants. *Salmonella* shares drop sharply as the number of management-determined actions rises from zero to one in three of the four industries.[13] This lower *Salmonella* share is followed by a modest, if any, decline in *Salmonella* shares after one management-determined action. The data also show that larger plants tend to have more management-determined actions than smaller ones. Combined, these trends suggest a possible relationship between plant size and *Salmonella* shares. It is hard to say if any relationship between specific process regulations, management-determined actions, and *Salmonella* shares exists.

Appendices A and B detail an empirical model of the reduced-form production function discussed in the previous section and describe the empirical methodology. The variables included in the model follow from discussions of process regulations and management-determined actions defined in table 4 and are given in equation B.1.

[12] As pointed out by a reviewer, there are many measures of food safety and *Salmonella* shares is only one of them.

[13] As pointed out by an anonymous reviewer, all plants have management actions that are chosen to meet specific needs. For example, large plants may focus on different actions than small plants. Here, we can only examine management actions considered in the ERS survey, but we believe they cover a variety of actions able to accommodate plants of many different sizes.

Table 3

Salmonella shares decline as the number of management-determined actions and plant size rise, 2000[1]

Industry	Number of management-determined actions: 0	1	2	3	4	5	Industry mean
	Mean percent of samples testing positive for Salmonella *spp.*						
Cattle carcass	22.0	0.0	1.0	1.0	0.0	n.a.	1.3
Ground beef	2.0	5.7	3.3	3.3	n.a.	n.a.	4.1
Hog carcass	43.9	8.0	6.6	3.7	6.0	0.0	7.0
Broilers	23.9	9.2	12.7	12.1	8.3	n.a.	11.8
Mean *Salmonella* share	14.6	6.4	5.3	4.9	5.7	0.0	5.8
	Mean plant size						
Cattle carcass (thousands of head)	14	64	106	155	329	n.a.	139
Ground beef (millions of pounds)	12.1	13.2	98.3	144.4	n.a.	n.a.	71.9
Hog carcass (thousands of head)	201	867	682	850	1,456	123	796
Broilers (millions of birds)	18.4	29.9	37.9	38.8	47.1	n.a.	38.1
	Number of management-determined actions						Total plants,
	0	1	2	3	4	5	all actions
	Number of plants						
Cattle carcass	2	4	34	35	6	0	81
Ground beef	8	46	38	30	0	0	122
Hog carcass	2	22	31	22	4	1	82
Broilers	3	7	18	22	22	0	72
Total plants[2]	15	79	121	109	32	1	357

n.a.= Not applicable.

[1] Management-determined actions include increases in human or physical capital, use of food safety process control technologies, vertical integration, contracting for enhanced food-safety with suppliers, and contracting for enhanced food safety with buyers. Only five statistically significant management-determined actions affect *Salmonella* spp. shares in each industry. Further discussion given in the text.

[2] Total number of plants in the ERS survey that underwent testing for *Salmonella* spp. in 2000.

Source: Economic Research Service data.

Process Regulations, Management-Determined Actions, and Other Variables That Explain *Salmonella* Shares

Data for the process regulation variables (no SSOP noncompliances, no FC noncompliances, and HACCP noncompliance share) come from the FSIS inspection reports completed by FSIS inspectors. If plants do not comply with mandated SSOPs, FCs, or HACCP tasks, the inspector may issue a noncompliance report. FSIS maintains several categories of record-keeping. The precise categories used in the definition were provided by Ron Eckel and other regulatory experts at the FSIS Omaha, Nebraska Technical Center.[14] The variables representing SSOPs and FCs are binary variables because many, but not most, plants reported no SSOPs or FCs out of compliance with FSIS regulations. Since the vast majority of plants had at least one noncompliance report for HACCP, the HACCP variable was defined as the number of HACCP tasks out of compliance with FSIS regulations divided by the total number of HACCP tasks performed.

[14] The SSOPs come from FSIS process codes 01B02 and 01C02, and the FCs come from FSIS process codes 06D02, 06D03, 06E01, 06F01, 06F02, and 06G01. HACCP tasks for slaughter operations include tasks identified in FSIS process codes 03B01, 03B02, 03C01, 03C02, 03J01, and 03J02.

Most of the management-determined action variables come from a meat and poultry food safety technology survey conducted by ERS (http://www.ers.usda.gov/Data/haccpsurvey/). Only variables representing vertical integration, size, and the presence of multiple processes come from elsewhere—the Enhanced Facilities Database (EFD) of FSIS.

The food safety (FS) labor share variable (FS labor share) indicates the share of food safety workers devoted to process control. Studies showing improved food safety process control at plants like Hatfield Meats led us to include a human capital variable—employee actions—that captures employee involvement in maintaining meat and poultry food safety process control (see p. 6, "Management-Determined Actions and *Salmonella* spp. Performance Standards"). The physical capital variable (high capital expenditures) and the variable measuring the extent to which plants may have remodeled to enhance meat and poultry food safety process control (change plant layout) are based on questions in the ERS survey. They asked whether plants made investments beyond those which plant managers believed were necessary for compliance with the PR/HACCP rule and the extent to which the plant changed its layout to enhance product flows.

Food safety process technology represents meat and poultry food safety process control technologies for different industries. Definitions vary for each industry (table 4) and are based on responses to the ERS survey. Technology indices for cattle slaughter and ground beef give a comprehensive measure of technologies, such as food safety equipment, and come from Ollinger, Moore, and Chandran (2004). The indices are based on the idea that some technologies in some industries work best as a group rather than as individual units, representing a "multiple hurdle system." Indices were created for sanitation, operating practices, equipment or sprays that control or kill pathogens, and, for cattle carcass plants, hide-removal practices. Each index is based on the use of several similar, yet distinct, technologies. For example, the sanitation index includes how often hands are washed and knives sanitized.

Table 4
Explanation of variables

Label (Appendix A equation 3)	Basis[1]	Label type	Definition
Independent variable: *Salmonella* share	S	Continuous	Number of samples testing positive for *Salmonella* spp. divided by number of samples tested.
Process regulation:			
No SSOP noncompliances	R	Binary	One for plants with no SSOPs out of compliance with FSIS requirements; zero otherwise.
No FC noncompliances	R	Binary	One for plants with no facility control tasks out of compliance with FSIS requirements; zero otherwise.
HACCP noncompliance shares	R	Continuous	Number of HACCP tasks not in compliance with FSIS requirements as a share of all HACCP tasks.
Discretionary labor—			
Labor share comprised of FS workers	L	Continuous	Number of food safety (FS) process control workers hired after 1996 as a share of all workers hired after 1996. They may or may not be trained to monitor HACCP performance.
Human capital—			
Employee actions	K	Binary	One if production workers correct own unsanitary conditions, tell others about their unsanitary conditions, or report conditions to supervisors; zero otherwise.
Physical capital—			
High capital expenditures	K	Binary	One if FS fixed investment exceeds that required under PR/HACCP; zero otherwise.
Change plant layout	K	Binary	One if plant modified processing facilities for pathogen control since 1996; zero otherwise.
Process technology—			
Food safety processing technology	τ	Continuous or binary	Varies; index values for hide-removal for cattle carcass and food safety processing equipment for ground beef. One for hog plants using steam vacuum units and one for broiler plants with seven food safety processing technologies; zero otherwise.
Organization—			
Vertical integration	O	Binary	Varies; one for cattle plants with ground beef operations, ground beef plant with slaughter operations, and hog or broiler with further processing operations; zero otherwise.
Supplier contract	O	Binary	One if supplier must meet plant FS standards; zero otherwise.
Buyer contract	O	Continuous	Probability of a plant's having a buyer contract in which a plant's customers impose stricter FS requirements on the plant than those imposed on it by FSIS or the plant produces branded products.
Plant technology:			
Size	P	Continuous	Number of animals slaughtered (cattle/hog carcasses, broilers) or pounds of meat produced (ground beef).
Multi-process	P	Binary	One if cattle, hog, broiler plant slaughters more than one animal species or ground beef plant produces further processed products; zero otherwise.
Control variables:			
Share samples, first quarter	X	Continuous	Share of *Salmonella* spp. samples taken from January to March.
Share samples, third quarter	X	Continuous	Share of *Salmonella* spp. samples taken from July to August.
Previous FSIS testing	X	Binary	One if previously subject to *Salmonella* spp. tests; zero otherwise.
Year testing conducted	X		One for test results from 2001; zero otherwise.
Western plant	X	Binary	One if plant located in Colorado, Idaho, Oklahoma, Texas, Utah, or Wyoming; zero otherwise.
Western Corn Belt plant	X	Binary	One if plant in Iowa, Kansas, Minnesota, Missouri, Nebraska, North or South Dakota; zero otherwise.
Cow/bull plant	X	Binary	One if cattle plant processes cows and bulls; zero otherwise.

[1] These variables are included in Appendix A equation 2, which serves as the justification for the associated empirical variable. S is a food safety variable, R is a vector of food safety process regulations, L is a vector of discretionary labor variables, K is a vector of physical and human capital variables, τ is vector of innovative technologies devoted to food safety, O is a vector of organizational relationship variables, P is a vector of plant technology variables, and X is a vector of control variables.

The seven types of food safety control equipment for poultry slaughter establishments comprise a multiple-hurdle system in which continuous applications of food safety process control equipment results in lower pathogen levels. Systems with fewer than all seven types of equipment may not work as well because pathogens may have time to recover before the poultry encounters the next type of pathogen control equipment.[15] The equipment controls pathogens by either limiting human contact or applying chemicals. The units include:

- A counter-flow scalding tank.
- An automatic transfer to the eviscerator conveyor.
- Viscera separation machinery.
- Equipment that pushes the crop through the front of the bird.
- Chlorinated water in the chiller.
- Inside-outside antimicrobial sprays.
- On-line reprocessing for contamination control.

There is no reason to believe that any particular type of equipment is superior to another; thus, we assume equivalency across all types of equipment.

We also evaluated the effects of many food safety technology variables, but only two—steam vacuum units on hog carcasses and the use of seven types of food safety control equipment in young chickens—had measurable effects on pathogens. Steam vacuum units for hog carcasses heat a carcass's surface high enough to kill pathogens and then remove any condensation with a vacuum system.

Recall that vertical integration and supplier and buyer contracts are management technologies in which plant managers can control food safety quality more closely. Vertical integration refers to either backward integration into slaughtering by ground beef plants or forward integration for cattle and hog carcass and broiler plants into processing (e.g., ground beef for cattle carcass plants). Supplier contracts relate to agreements up the supply chain. Animal suppliers, for example, might commit to using fencing to prevent rodents from entering animal pens or take other food-safety-related measures. If the animal supplier does not uphold its food safety promises, it may lose a customer and future revenues if managers of the buying plant choose to purchase animals elsewhere. Buyer contracts bind plants to buying firms (buyers), such as fast food restaurants, major grocery stores, and other meat and poultry retailers and wholesalers, that need to protect their reputations for food safety. Under these contracts, a buyer might require plant managers to take specific preventive and corrective actions, such as product testing or more stringent cleaning, that exceed the actions required by FSIS. Data on the use of these contracts came from the ERS survey. The question upon which buyer contracts are based asks specifically whether the terms of the contract required the plant to perform tasks that were more demanding than those imposed by FSIS.

[15] We determined that plants needed all seven types of equipment through trial and error. Fewer than seven types of equipment did not yield any significant change in the share of samples testing positive for *Salmonella* whereas seven types of equipment did lower the share of positive *Salmonella* samples.

Buyer contracts affect a plant's operations by making managers more vigilant about controlling pathogens. For example, instead of asking employees just to wash their hands, a plant may also require the employee to sanitize his/her knives more frequently. Plant managers feel pressure to act because they fear that a buyer will shift purchases to competitors. We call this increase in management diligence the management effect.

There is also a technology effect in which a buyer may require a plant to make capital investments, buy food safety process control equipment, or make some other change intended to enhance food safety process control. Since some economists may prefer to separate the management effect from the technology effect, we created an instrumental variable to represent the management effect. It is defined as the probability of a plant's having a buyer contract.[16]

The final two groups of variables, plant technology and control variables, are also defined in table 4. Plant technology variables are determined by the volume of output (size) and by a plant's product line (multiprocess). Control variables account for unique factors, due mainly to either the season of the tests or the geographic location of the plant. We also control for:

- Plant testing experience: plant managers may improve their food safety process controls after their first round of testing.
- Quarter of the year and geographic location: FSIS (2005) indicates that *Salmonella* spp. levels can vary with the time of the year, and Onal, Unnevehr, and Bekric (2000) found that *Salmonella* spp. levels vary geographically.
- Control variables: most are used for only one or two industries and only after finding a statistically significant impact in the reported regression analyses.

[16] An anonymous reviewer pointed out that the technology effect might be associated with other management-determined actions included in the model and that this technology effect would reduce the impact of capital investments and processing technologies on the dependent variable. This is not a drawback. Rather, it is precisely what should happen since there would be no such technology without a contract. Nonetheless, we estimated the management effect of buyer contracts separately with an instrumental variable approach in which we regressed buyer contracts on the independent variables in the equation from Appendix B, a market size variable (whether the plant serves national or local markets), and a number of technology variables not related to *Salmonella* shares. The resulting estimator captures greater management vigilance only and is free of any association with specific food safety processing technologies or capital or labor investments. This buyer contract variable is defined as the probability of a plant's having a buyer contract.

Combining Several Datasets With Unique Data on Food Safety Technologies

FSIS data include the total number of samples tested by FSIS in 2000 and the number of test samples found to be positive for *Salmonella* spp. For cattle carcass plants, we also used 2001 data because we have data for only 40 plants in 2000. FSIS regulatory compliance data, also called noncompliance reports, covered the same years as the *Salmonella* spp. data and included the number of SSOP, HACCP, and facility control tasks out of compliance with FSIS standards, the number of tasks performed, and other process control data. The FSIS Enhanced Facilities Database (EFD) for 2000 gives detailed information on the numbers and types of animals slaughtered, SIC codes (Standard Industrial Classification), 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 EFD and regulatory compliance dataset include data for the more than 6,000 plants inspected by FSIS. Far fewer observations of plants, however, were included in the analysis because many plants in the EFD do not produce carcasses or ground meat, were not tested for *Salmonella* spp. in 2000, or had missing data.

We also deleted observations of plants testing in the B, C, or higher sets. Recall that FSIS randomly selects plants for *Salmonella* spp. testing in an initial set of tests ("A" set) and, if the plant fails the "A" set, it is subjected to followup sets. Since only "A" set plants are randomly selected, we use only "A" set plants in the analysis and drop other nonrandomly selected sets.[17] Thus, plants eligible for our analysis had to have undergone *Salmonella* spp. testing in the year 2000 (2000 or 2001 for cattle carcasses), had been subject to testing in the "A" set, and had been a producer of cattle or hog carcasses, broilers, or ground beef. Note, if a plant was in the middle of a test set at either the beginning or end of the year, the *Salmonella* spp. samples from the previous or subsequent year were included to make a complete set; thus, the dependent variable **S** for any plant is always based on a complete set of samples. After deletions for incomplete data, 162 cattle carcass, 646 ground beef, 175 hog carcass, and 162 broiler plants were eligible for the analysis.

[17] If we were to include B, C, and D tests, then we would bias our sample toward plants that are less able to pass the *Salmonella* test because the sample would include more poor performers than would randomly occur.

The Economic Research Service (ERS) 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 ERS survey covered only establishments in the EFD that ERS defined as manufacturers—about a third of the establishments inspected by FSIS.[18] Excluded establishments included retailers, wholesalers, and other nonmanufacturers. About 60 percent of the population of plants selected by ERS responded to the survey. Data used in the analysis included data from 131 ground beef plants, 73 hog carcass plants, and 72 broiler plants that underwent *Salmonella* spp. testing in 2000 and 73 cattle carcass plants that had *Salmonella* spp. testing in 2000 or 2001. These data accounted for 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 (131 of the 641 ground beef plants eligible for analysis) is due to the wide diversity of establishments that grind meat. For example, many grocery stores and wholesalers grind meat as a side business.

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.[19] 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.

[18] 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.

[19] An anonymous reviewer asserts that a large degree of heterogeneity in the operations of establishments would increase the bias.

Descriptive Statistics

Table 5 provides the means of the variables. Notice that the share of meat and poultry samples testing positive for *Salmonella* spp. ranged from about 1.4 percent for cattle carcasses to nearly 12 percent for broilers. The table also shows that nearly all broiler plants were vertically integrated, more than half of all plants in each industry had buyer contracts, and workers in cattle slaughter plants had much greater control over food safety process control (employee actions) than employees in other industries.

Table 5
Means of all variables used in models

Variable	Variable type	Product category: Cattle carcass	Ground Beef	Hog carcass	Broiler
Dependent variable:					
Salmonella share	Continuous	0.014	0.041	0.070	0.118
Process regulation:					
No SSOP noncompliances	Binary	0.086	0.115	0.073	0.026
No FC noncompliances	Binary	0.160	0.197	0.134	0.038
HACCP noncompliance share	Continuous	0.020	0.007	0.011	0.057
Management-determined actions:					
Discretionary labor—					
Labor share comprised of FS workers	Continuous	0.021	0.020	0.028	0.056
Human capital—					
Employee actions	Binary	0.827	0.631	0.573	0.513
Physical capital—					
High capital expenditures	Binary	0.407	0.344	0.280	0.436
Change plant layout	Binary	n.a.	n.a.	n.a.	0.795
Process technology—					
Food safety processing technology: hide-removal index	Continuous	0.439	n.a.	n.a.	n.a.
Food safety processing technology: food safety equipment index	Continuous	n.a.	0.520	n.a.	n.a.
Food safety processing technology: uses steam vacuum unit	Binary	n.a.	n.a.	0.122	n.a.
Food safety processing technology: seven equipment types	Binary	n.a.	n.a.	n.a.	0.038
Organization—					
Vertical integration: makes ground beef	Binary	0.395	n.a.	n.a.	n.a.
Vertical integration: slaughters animals	Binary	n.a.	0.369	n.a.	n.a.
Vertical integration: further processes meat	Binary	n.a.	-	0.512	0.987
Supplier contract	Binary	n.a.	0.279	0.220	0.590
Buyer contract	Continuous	0.852	0.746	0.659	0.577
Plant technology—					
Size: animals slaughtered[1]	Continuous	0.139	n.a.	0.796	0.038
Size: pounds of ground meat[2]	Continuous	n.a.	0.072	n.a.	n.a.
Multiprocess: slaughters multiple species	Binary	0.370	n.a.	0.659	0.218
Multiprocess: produces multiple processed products	Binary	n.a.	0.606	n.a.	n.a.
Control variables—					
Share samples, first quarter	Continuous	n.a.	0.238	0.445	0.559
Share samples, third quarter	Continuous	0.259	n.a.	n.a.	n.a.
Had *Salmonella* spp. testing	Binary	n.a.	0.426	n.a.	0.846
Year of *Salmonella* spp. testing	Binary	0.494	n.a.	n.a.	n.a.
Western plant location	Binary	0.247	n.a.	n.a.	0.090
Western Corn Belt plant location	Binary	n.a.	n.a.	n.a.	0.103
Cow/bull plant	Binary	0.617	n.a.	n.a.	n.a.

n.a. = Not applicable.
[1] Cattle and hog carcasses are in millions and broilers are in billions.
[2] Ground beef is in billion pounds.
Source: Economic Research Service technology data and various FSIS data sources.

Results

Process Regulation Variables

Results (table 6) indicate that cattle and hog carcass plants with no SSOP noncompliance reports were associated with a statistically significant, lower percentage of samples testing positive for *Salmonella* spp. Plants with no FC noncompliance reports were associated with a marginally significant, lower percentage of samples testing positive for *Salmonella* spp. in hog carcass plants, but a significantly higher percentage of samples testing positive for *Salmonella* spp. in broiler plants. Table 6 also shows that the share of tasks not in compliance with HACCP plans had a statistically significant and positive effect on the number of samples testing positive for *Salmonella* spp. in cattle carcass, ground beef, and broiler plants.

Table 7 shows the impact of regulations and actions on *Salmonella* shares with a 20-percent increase in the stringency of process regulations and management-determined actions (see box, p. 25, "Analytical Approach to Econometric Analysis"). Results show that SSOPs have their largest hypothetical effect in hog carcasses. A 20-percent increase in the number of plants with no SSOP noncompliance reports was associated with a 17-percent reduction in *Salmonella* share.[20] HACCP noncompliance share had its greatest impact in cattle carcasses. A 20-percent increase in the HACCP noncompliance share was associated with an 18.5-percent increase in the *Salmonella* share.[21]

The regulatory impact varies by industry. SSOP noncompliance reports had no statistically significant association with the *Salmonella* share in ground beef and broilers, and the HACCP noncompliance share had no statistically significant association with the *Salmonella* share in hog carcasses (table 6). Only in cattle carcasses were plants with no SSOP noncompliance reports and HACCP noncompliance shares of the correct sign and significant. Plants with no FC noncompliance reports had mixed results, suggesting little impact—one empirical result was significant and of the correct (negative) sign and one was significant and of the incorrect (positive) sign.

Discretionary Labor and Human and Physical Capital

Results show that a higher labor share was associated with a statistically significant increase in *Salmonella* spp. in cattle carcass and ground beef plants, but had no impact in the other industries (table 6). This is contrary to what was expected, perhaps because cattle carcass and ground beef plants added meat and poultry food safety workers in an effort to reduce *Salmonella* spp. when they already had high *Salmonella* shares.

Human and physical capital gave expected results. Cattle and hog carcass plants that permitted employee actions had a lower share of samples testing positive for *Salmonella* spp. (table 6). Also, greater investment in plant, property, and equipment than required for compliance with the PR/HACCP rule in cattle carcass and ground beef plants and changes in plant layout in broiler plants were associated with statistically significant and negative impacts on the share of samples testing positive for *Salmonella* spp.

[20] We computed the marginal effects of binary and continuous variables in the same way to weigh all independent variables equally. For binary variables, the right-hand side of table 7 is multiplied by 0.20 and the mean of the independent variable is the mean of the binary variable.

[21] We assume linearity, such that a 20-percent reduction in the noncompliance share has an equal and opposite effect on the *Salmonella* share as for a 20-percent increase in noncompliance.

Analytical Approach to Econometric Analysis

Regression analysis was used to evaluate the impact of process regulations and management-determined actions on *Salmonella* shares in the meat and poultry industry. Each of the four industries—cattle and hog carcass, ground beef, and broilers—were examined separately because they have different processing technologies and *Salmonella* spp. standards. The hog carcass, ground beef, and broiler plant analyses were based on 2000 data because ERS data were available only for that year. The analyses also relied on FSIS's Enhanced Facilities Database (EFD) data for 2000. Since there were not enough cattle carcass observations for a 1-year analysis, *Salmonella* spp. and process regulation data for 2000 and 2001 were used.

Tobit regressions and STATA econometric software were utilized to conduct the analysis. The Tobit regressions are discussed in more detail in appendix B. STATA allowed us to use the sample weights that were calculated as proposed by Gelman and Carlin and gives both parameter values and marginal effects. Marginal effects are reported because they provide a way to estimate the impact of the independent variables on the dependent variable in tobit regressions. For example, they allow us to report how much a 10-percent increase in an independent variable, such as a buyer contract, has on the *Salmonella* share.[1]

We used the following procedure:

1. We used a likelihood test to show that a model containing all of the process regulation and management-determined actions (independent) variables had a statistically significant impact on *Salmonella* shares. The results are available from the authors.

2. Parameter estimates and t-statistics from the econometric estimates model were then used to evaluate the impact of the independent variables on *Salmonella* shares (dependent variable). The coefficient on each variable is called the marginal effect and is used to determine the change in the dependent variable. The t-statistic indicates the degree of certainty associated with the estimated parameter.

3. We estimated the change in the share of samples testing positive for *Salmonella* spp. We multiplied the estimated coefficients (table 6) times 0.20 (20 percent) times the mean of the independent variable (e.g., HACCP noncompliance share-table 5) and divided both sides of the equation by the mean *Salmonella* share (table 5).[2]

Table 7 shows the hypothetical effect of 20 percent increases in independent variables on *Salmonella* shares. All variables with parameter signs consistent with their expected sign were included in the total impact, regardless of whether the parameter estimate was statistically significant. For example, an estimate of the impact of SSOPs on *Salmonella* shares in broilers was included even though the parameter estimate was not statistically significant. An estimate of the HACCP noncompliance share for hog carcasses, on the other hand, was not included because the parameter is negative and a positive sign was expected.[3]

[1] In ordinary least squares regressions, the impact of independent variables on the dependent variable can be computed directly from parameter values because the statistical distribution of the dependent variable is a full distribution. However, parameter values for tobit regressions cannot be used in the same way because they are estimated for an independent variable with a truncated distribution (*Salmonella* test results exist only in the positive portion of the distribution of the dependent variable, S). Econometricians, such as Greene (1993), have derived measures that do define direct impact. These marginal effects are presented in table 6. STATA, our econometric statistical package, constructs these marginal effects by evaluating continuous variables at their means and estimating binary variables as discrete changes from zero to one.

[2] The percent change could have been any value as long as the change was identical for each variable. The goal was to estimate the impact of process regulations relative to management-determined actions.

[3] An anonymous reviewer points out that this could bias the results if statistically insignificant values are used for estimation purposes. We use insignificant but theoretically consistent terms because we are talking about an average relative contribution and not an absolute relative contribution.

A 20-percent increase in employee actions led to a 122-percent decline in *Salmonella* spp. in cattle carcasses. Broilers and hog carcasses showed declines of 16.0 and 1.5 percent, respectively (table 7). By contrast, a 20-percent increase in the number of plants that made high physical investments or changed their plant layouts led to reductions in *Salmonella* spp. of 54.0, 7.9, and 7.5 percent in cattle carcasses, ground beef, and broilers, respectively.[22] There was no impact in hog carcasses.

Food Safety Processing Technologies

Numerous stand-alone meat and poultry food safety technologies and meat and poultry food safety technology indices were examined, but only a few were statistically significant. All of the food safety processing technology variables we examined were recommended by at least one expert and were reported in the ERS technology survey. Test reports for some equipment also showed reductions in pathogens. For example, steam pasteurizers for cattle carcasses have been associated with statistically significant declines in pathogens. Several technology indices were also considered (see earlier discussion).

Cattle carcass plants with higher index values for hide removal were associated with a statistically significant lower share of samples testing positive for *Salmonella* spp., as were broiler plants that used the seven types of poultry processing equipment designed for better pathogen control. Hog carcass plants that use steam vacuum units and ground beef plants with a high food safety equipment index had statistically insignificant declines in *Salmonella* spp.

None of the stand-alone equipment tested, including steam pasteurizers, steam vacuums, sanitizing washes, and other equipment identified in Ollinger, Moore, and Chandran (2004), significantly reduced the number of positive test samples. Groups of technologies working in concert in broiler and cattle carcass plants did provide superior process control and support for meat and poultry food safety experts who promote the use of multiple technologies to control pathogens.

As shown in table 7, a 20-percent increase in the hide-removal index is associated with about a 45-percent decline in samples testing positive for *Salmonella* spp. in cattle carcasses. Additionally, a 20-percent change in the equipment index in ground beef, number of plants using steam vacuum units in hog carcasses, and number of plants using seven food safety technologies in broilers was associated with reductions in the share of samples testing positive for *Salmonella* spp. that varied from 7.6 percent in ground beef to 0.9 percent in broilers.

Organizational Arrangements, Plant Technology, and Control Variables

Results for organizational arrangement variables show that cattle carcass plants that vertically integrated into ground beef production, hog carcass plants that integrated into processing, and ground beef plants that backward integrated into slaughter had a statistically significant lower share of samples

[22] Small changes in the samples testing positive for *Salmonella* spp. may only be applicable in the cattle slaughter regression because large changes may be out of the statistically valid region. However, because our main interest is to evaluate the contributions of the independent variables relative to each other (i.e., process regulations relative to employee actions), it does not matter whether we change the independent variables by 2 percent, 20 percent, or 200 percent as long as we change all independent variables by the same amount. We used 20 percent because it is an easy number to work with and gives reasonable results for the other three products.

Table 6

The marginal effects of process regulations and management-determined actions on *Salmonella* shares, by type of meat or poultry plant, 2000[1]

Variable	Cattle carcass	Ground beef	Hog carcass	Broilers
Process regulation:				
No SSOP noncompliances	-0.088***	0.018	-0.629***	-0.096
	(0.018)	(0.025)	(0.107)	(0.217)
No FC noncompliances	-0.002	-0.020	-0.099*	0.119***
	(0.010)	(0.029)	(0.060)	(0.030)
HACCP noncompliance share	0.649***	2.114**	-0.002	0.354*
	(0.193)	(1.078)	(0.567)	(0.220)
Management-determined actions:				
Discretionary labor—				
Labor share comprised of food safety workers	0.866***	1.073***	0.109	-0.647
	(0.164)	(0.362)	(0.080)	(1.36)
Human capital—				
Employee actions	-0.111***	0.014	-0.098***	-0.017
	(0.014)	(0.016)	(0.037)	(0.017)
Physical capital—				
High capital expenditures	-0.093***	-0.047***	0.118**	-0.022
	(0.015)	(0.017)	(0.048)	(0.017)
Change plant layout	n.a.	n.a.	n.a.	-0.044*
				(0.029)
Process technology—				
Food safety processing technology[2]	-0.071***	-0.030	-0.069	-0.143***
	(0.024)	(0.021)	(0.056)	(0.040)
Organization—				
Vertical integration[3]	-0.128***	-0.042***	-0.083*	0.039
	(0.024)	(0.016)	(0.045)	(0.029)
Supplier contract	n.a.	-0.027*	-0.023	-0.025+
		(0.018)	(0.042)	(0.017)
Buyer contract	-0.077***	-0.030	-0.182**	-0.047*
	(0.012)	(0.025)	(0.077)	(0.028)
Plant technology:				
Size	-0.711***	0.045	-0.024**	-0.777*
	(0.287)	(0.04)	(0.011)	(0.440)
Multi-process[4]	0.010	0.012	-0.144**	0.040
	(0.011)	(0.014)	(0.048)	(0.027)
Control variables:				
Share samples, first quarter	n.a.	0.098***	-0.104	-0.144***
		(0.038)	(0.096)	(0.039)
Share samples, third quarter	0.189***	n.a.	n.a.	n.a.
	(0.034)			
Had *Salmonella* spp. testing	-0.002	-0.040	n.a.	0.008
	(0.011)	(0.034)		(0.019)
Year of *Salmonella* spp. testing	-0.011	n.a.	n.a.	n.a.
	(0.001)			
Western plant location	0.176***	n.a.	n.a.	-0.134***
	(0.027)			(0.042)
Western Corn Belt plant location	n.a.	n.a.	n.a.	-0.134*
				(0.076)
Cow/bull plant	0.172***	n.a.	n.a.	n.a.
	(0.036)			
Observations[5]	73	124	73	72
X^2	436***	32**	73**	252***

+, *, **, *** statistically significant at the 20, 10, 5, and 1 percent level, respectively.

n.a. = Not applicable. Dependent variable: S (share of samples testing positive for *Salmonella* spp. in FSIS testing program).

[1] For marginal effects, continuous variables are evaluated at the means and binary variables are computed as discrete changes from zero to one. Standard errors are in parentheses.

[2] Food safety processing technology is a hide-removal index for cattle slaughter, equipment index for ground beef, and one for hog carcass plants that use steam vacuum units and broiler plants that use seven types of modern chicken slaughter equipment; zero otherwise.

[3] Vertical integration equals one for cattle carcass plants that grind meat, ground meat plants that slaughter animals, and hog carcass and chicken broiler plants that further process meat; zero otherwise.

[4] One if a cattle, hog, broiler plant slaughters more than one animal species or a ground beef plant produces further processed products; zero otherwise.

[5] The total number, 342 plants, is less than the 356 plants reported in table 3 because some plants had incomplete data and were dropped.

Source: Economic Research Service estimates.

testing positive for *Salmonella* spp. than did other plants. Table 7 shows that a 20-percent increase in the number of vertically integrated plants producing cattle carcasses was associated with a 72.2-percent reduction in the share of samples testing positive for *Salmonella* spp. Ground beef and hog carcass plants experienced *Salmonella* reductions of 7.6 and 12.1 percent with a 20-percent increase in the number of vertically integrated plants.

Results also show that ground beef and broiler plants with food-safety-related supplier contracts had significantly fewer samples testing positive for *Salmonella* spp. Hog carcass plants had a negative but insignificant relationship. A 20-percent increase in the number of plants with supply contracts

Table 7
Reductions in *Salmonella* share if independent variables are changed by 20 percent, by product category [1]

Source of impact	Variables	Cattle	Ground beef	Hog carcass	Broiler	Mean[2] (no cattle)
				Salmonella *share*		
Process regulation	No SSOP noncompliances + No FC noncompliances	11.3	1.9	17.0	0.4	6.5
	HACCP noncompliance share	18.5	7.2	No effect	3.4	3.5
Total process regulation		29.8	9.1	17.0	3.8	10.0
Management-determined actions:						
Capital— Human capital	Employee actions	132.2	No effect	16.0	1.5	5.9
Physical capital	High capital expenditures + change plant layout	54.0	7.9	No effect	7.5	5.1
Sum of capital		186.2	7.9	16.0	9.0	11.0
Process technology:	Food safety processing technology[3]	44.5	7.6	2.4	0.9	3.6
Sum of process technology		44.5	7.6	2.4	0.9	3.6
Organization:	Vertical integration[4]	72.2	7.6	12.1	No effect	6.6
	Supplier contract	No effect	3.7	1.4	2.5	2.5
	Buyer contract	93.6	10.9	34.3	4.6	16.6
Sum of organization		165.8	22.2	47.8	7.1	25.7
Sum of all management-determined actions		396.5	37.7	66.2	17.0	40.3
Maximum effect—all factors		426.8	46.8	83.2	20.8	50.3

[1] Estimates are based on a 20-percent change in all independent variables. Using a HACCP noncompliance share as an example, percentage change in S = β*0.20* HACCP noncompliance share / *Salmonella* share, where HACCP noncompliance share and *Salmonella* share are sample mean values (table 5).
[2] Mean values based on ground beef, hogs, and broilers. Cattle slaughter excluded because it gives too much influence over the mean values.
[3] Food safety processing technology is a hide-removal index for cattle slaughter, equipment index for ground beef, and one for hog carcass plants that use steam vacuum units and broiler plants that use seven types of modern chicken slaughter equipment; zero otherwise.
[4] Vertical integration equals one for cattle carcass plants that grind meat, ground meat plants that slaughter animals, and hog carcass and chicken broiler plants that further process meat; zero otherwise.
Source: Economic Research Service estimates.

was associated with a 3.7-, 1.4-, and 2.5-percent reduction in samples testing positive for *Salmonella* spp. in ground beef, hog carcasses, and broilers, respectively (table 7).

Table 6 shows that the probability of having a buyer contract is associated with significantly fewer samples' testing positive for *Salmonella* spp. The impact of a 20-percent increase in the probability of having a contract varied from 4.6 percent fewer samples testing positive for *Salmonella* spp. in broiler plants to 93.6 percent in cattle carcass plants (table 7).[23]

[23] Recall that we are using the probability of having a buyer contract as an instrumental variable for buyer contracts. Parameter estimates for this variable are nearly identical to the binary variable for buyer contracts.

Results (table 6) also show that cattle and hog carcass and broiler plants, but not ground beef plants, realized reductions in the share of samples testing positive for *Salmonella* spp. as plant size rose. A 20-percent increase in plant size was associated with a 141-percent reduction in *Salmonella* spp. for cattle carcasses and about a 5.4- and 5.0-percent reduction for hogs and broilers.

One plausible explanation for the advantage to larger plants is that they have a much lower cost of purchasing and maintaining quality control laboratories and other fixed-cost food safety technologies because the cost per unit of output drops as plant size rises. Ground beef plants, on the other hand, have few equipment-based food safety technologies available for *Salmonella* spp. control. Rather, they rely on methods that incur costs that vary with output. For example, they must ensure that incoming meat is not contaminated with pathogens and then rigorously clean and sanitize to avoid introducing or spreading pathogens.

Horizontal growth into multiproduct or multispecies plants did not affect shares of *Salmonella* spp. One of the coefficients for these multiprocess plants was negative, and three were positive. The control variables show that cows and bulls have a higher share of test samples testing positive for *Salmonella* spp. than do other cattle and that geography and seasonality of FSIS tests affect the share of samples testing positive for *Salmonella* spp.

Many other characteristics and technologies discussed in Ollinger, Moore, and Chandran (2004) were examined, but were not statistically significant and were dropped. For example, broiler and hog carcass plants often remove animals from feed prior to slaughter to reduce fecal matter, but our results show no discernible effect for this process. Finally, numerous variations of the SSOP regulatory variable were tested, but were dropped in favor of the one used in the model because results were similar and experts at FSIS had more confidence in the definition used. A continuous SSOP variable defined as tasks not in compliance with SSOPs as a share of all SSOPs and FCs not in compliance as a share of all FCs were also tested. Binary variables were used. We did test continuous variables, but results were insignificant in all cases, perhaps because of nonlinearity due to many plants' reporting no noncompliance reports.

Discussion of Results

Maximum Shares of *Salmonella* Controlled by Management-Determined Actions

The “maximum effect—all factors” is shown at the bottom of table 7. As indicated on p. 25 in the box “Analytical Approach to Econometric Analysis,” this value is the impact on *Salmonella* spp. due to a 20-percent increase in process regulations and all management-determined actions described in table 7. That is, the maximum effect is the most that process regulations and management-determined actions can affect *Salmonella* spp. levels if all factors were changed by 20 percent. For example, a 20-percent increase in the five relevant management-determined actions for broilers—human and physical capital, process technology, and supplier and buyer contracts would lead to a 17-percent reduction in the number of samples testing positive for *Salmonella* spp. For both process regulations and management-determined actions, the maximum effect for broilers is 20.8 percent. Notice that vertical integration is assumed to have no effect since the sign on its estimated coefficient does not match expectations.

The maximum effect for poultry is the smallest value; ground beef is nearly twice as high and hog slaughter four times higher than poultry. Cattle slaughter is dramatically higher than any of the other three industries, even though the coefficients for process regulation and management-determined action variables (table 6) do not vary greatly from those of poultry. One possible explanation for this level of variance is that a 20-percent change in management-determined actions in cattle slaughter is out of the sample range. These changes may also have a greater proportional impact in cattle carcasses and a smaller impact in broilers because the mean share of samples testing positive for *Salmonella* spp. is higher in broilers, making any percentage change in the share of samples testing positive for *Salmonella* spp. smaller with relatively equal absolute reductions.

The relative effect of process regulation and management-determined actions gives the percentage contribution of each type of process regulation and industry action. The method of calculation is given in the box “Computing the Maximum Effect: All Factors and the Relative Shares” p. 31 and the percentages in the Appendix C table. For ease of presentation, the relative contribution shares are included in figures 2-6.

Consider the shares of process regulations and management-determined actions. As shown in figures 2-6, process regulation varies from a relative contribution of about 7 percent in cattle carcasses to 20 percent in hog carcasses. By contrast, the relative effect of human and physical capital varied from 19 percent in hog carcasses to about 44 percent in broilers and cattle slaughter, food safety technology ranged from 2.9 percent in hog carcasses to 16.2 percent in ground beef, and organization’s contribution (vertical integration and contract with suppliers and buyers) varies from about 34 percent in broilers to nearly 58 percent in hog carcasses.

The figures show that food safety technologies are less effective than other management-determined actions, perhaps suggesting endogenous

Computing the Maximum Effect: All Factors and the Relative Share

The maximum effect—all factors is the sum of all of the changes to the *Salmonella* share due to a 20-percent increase in each process regulation and management-determined action variable. Only variables with an estimated sign on the coefficient that matched expectations were included in the sum. Ground beef, for example, includes FCs, which has a coefficient that matches expectations, but does not include SSOPs, which has a coefficient that does not match expectations. The sum for ground beef also excludes human capital because that positive coefficient differs from the expected negative value since human capital should reduce not increase the *Salmonella* spp. share.

The relative contribution to *Salmonella* spp. reduction (i.e., shares of the maximum effect—all factors as demonstrated in figs. 2-5), was obtained by dividing all cells of table 7 by the corresponding value in the maximum effect—all factors cell. This calculation provides a percentage called the percent (or share) of the maximum effect. For example, each cell of the table pertaining to broilers was divided by 20.8. The resulting percentages, shown in table 1 of Appendix C, indicate that process regulation accounts for about 18.3 percent of the maximum effect—all factors and that management-determined actions account for the remaining 81.7 percent.

technologies may need them the least and plants using more may have the greatest difficulty controlling pathogens. This minimalist approach to using food safety technology is consistent with its economic value. Plants that add equipment to improve product tastiness, texture, or some other observable food quality do so to increase sales or raise prices. Food safety, however, offers fewer direct economic benefits because consumers may assume all purchased meat and poultry is safe.[24]

[24] Companies that tend to invest less in food safety do make exceptions. They likely would make investments if consumers have reason to believe that food is not safe. For example, Sara Lee and a Conagra plant in Greeley, CO, improved their meat and poultry food safety technologies and controls only after they suffered recalls.

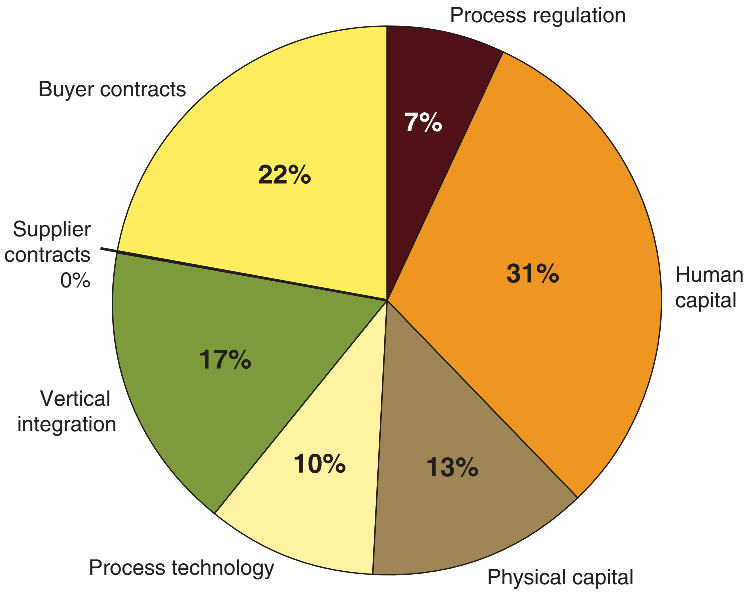
Actual Shares of *Salmonella* Controlled by Process Regulations and Management-Determined Actions

The maximum contribution to process control by process regulations and management-determined actions depends on whether plant managers take all such actions. Table 3 shows that they do not—the actual number of management-determined actions adopted is much lower. For example, 15 plants had no management-determined actions, 79 plants had only 1, and most plants (about 60 percent) had 2 or fewer management-determined actions (table 3). Fewer management-determined actions mean a relatively weaker influence by management-determined actions and a stronger influence by process regulations than that shown in figures 2-6.

Table 8 shows the changes in *Salmonella* shares by the number of management-determined actions for all four industries. If a ground beef plant, for example, took only two management-determined actions, then the reduc-

Figure 2

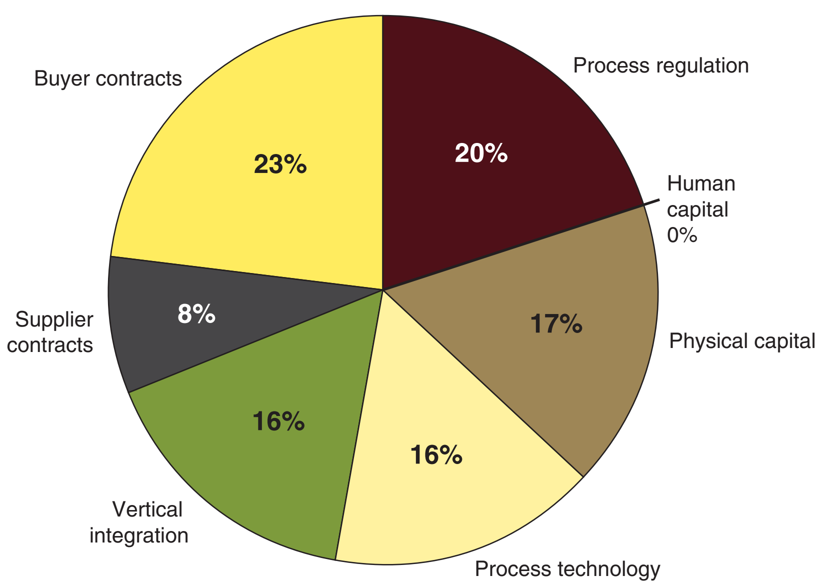
Cattle slaughter: Share of change due to process regulations and management-determined actions if all variables changed by the same amount



Source: Economic Research Service estimates.

Figure 3

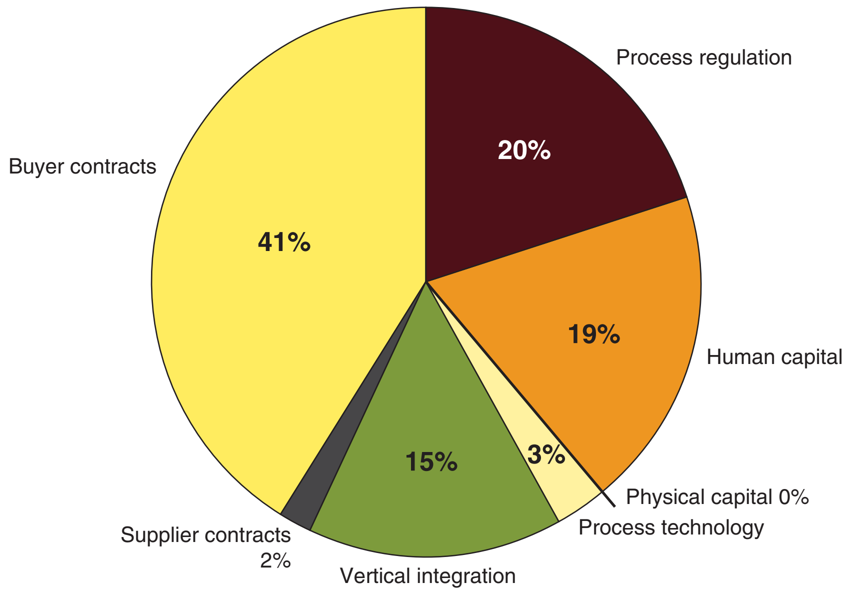
Ground beef: Share of change due to process regulations and management-determined actions if all variables changed by the same amount



Source: Economic Research Service estimates.

Figure 4

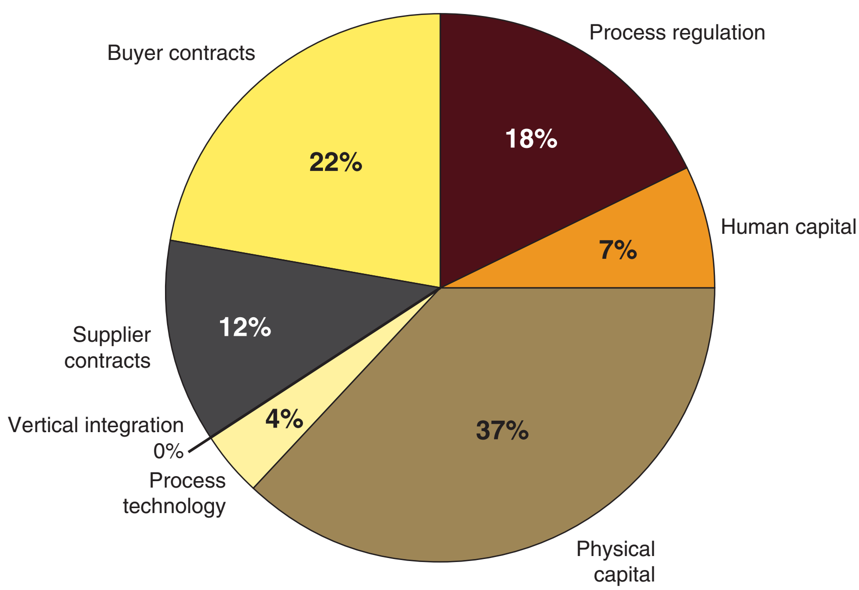
Hog slaughter: Share of change due to process regulations and management-determined actions if all variables changed by the same amount



Source: Economic Research Service estimates.

Figure 5

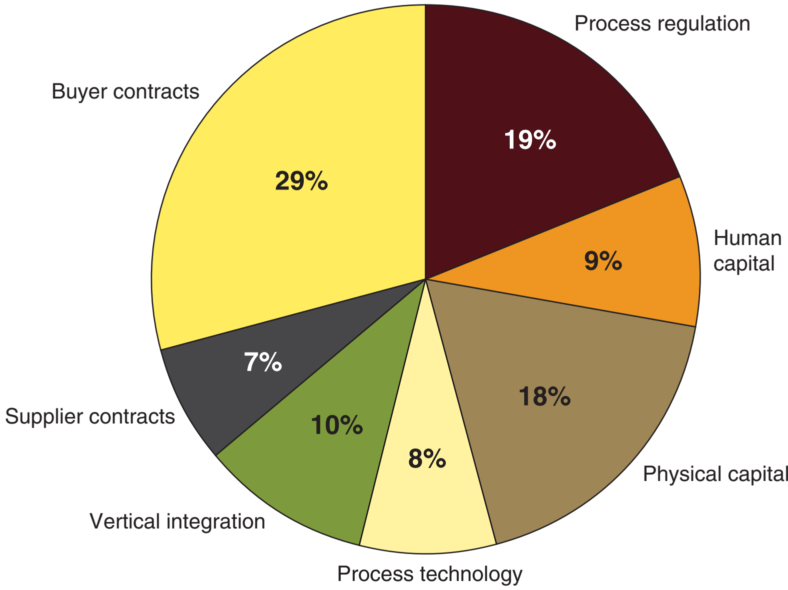
Broiler: Share of change due to process regulations and management-determined actions if all variables changed by the same amount



Source: Economic Research Service estimates.

Figure 6

Mean values (excluding cattle): Share of change due to process regulations and management-determined actions if all variables changed by the same amount



Notes:

1. Cattle slaughter excluded from chart of mean values because cattle slaughter gives too much influence over the mean values.
2. Values are the normalized values from table 7. They are normalized by dividing all independent variables by the maximum effect due to all factors. See Appendix C table for detailed presentation.
4. Processing technology is a hide-removal index for cattle slaughter and equipment index for ground beef. It also equals one for hog carcass plants that use steam vacuum units and broiler plants that use seven types of modern chicken slaughter equipment; zero otherwise.
5. Vertical integration equals one for cattle carcass plants that grind meat, ground meat plants that slaughter animals, and hog carcass and chicken broiler plants that further process meat; zero otherwise.

Source: Economic Research Service estimates.

tion in *Salmonella* shares due to management-determined actions for that plant would be about 16.9 percent. Since process regulations account for a 9.1-percent reduction in *Salmonella* shares (table 7), the contribution to *Salmonella* spp. reduction by management-determined actions and process regulations equals 26 percent (9.1 percent + 16.9 percent). Management-determined actions (16.9 percent) account for about two-thirds of *Salmonella* reduction; process regulation accounts for the remaining third of the total reduction.

Figure 7 shows the relative shares of process regulation and the comparison of management-determined actions with *Salmonella* reduction.[25] Plant managers taking no management-determined actions rely only on process regulation for food safety process control, making the process regulation share of *Salmonella* spp. reduction equal to 100 percent The mean share of *Salmonella* spp. reduction due to management-determined actions across all product categories moves up sharply from 0 to about 52 percent, and process regulation's share drops from 100 to 48 percent for the first management-determined action. The mean share of *Salmonella* spp. reduction due to

[25] Values are computed as follows. First, we found the actual value of management-determined actions. This actual value equals the sum of all values arising from management-determined actions actually taken by a plant. For example, suppose ground beef plant A is vertically integrated, has a buyer contract, and has high physical capital investment, then its actual management-determined actions value equals 7.9 percent plus 7.7 percent plus 10.9 percent (table 7) or 26.5 percent. Since process regulations equal 9.1 percent of *Salmonella* reduction (table 7), the actual process regulation effect must be adjusted. We do this by dividing process regulations (9.1 percent) by the sum of process regulations (9.1 percent) and actual management-determined actions (26.5 percent), which equals 34.6 percent. Thus, the actual process regulation effect equals 25.6 percent for this example.

management-determined actions rises more slowly as the number of management-determined actions increases. Overall, the mean share of *Salmonella* spp. reduction due to process regulation is about 34 percent and the mean share of *Salmonella* spp. reduction due to management-determined actions is about 66 percent.

Table 8 also shows that the impact of management-determined actions on food safety process control diminishes sharply after three actions, suggesting that food safety process control would increase substantially if plants currently taking two or fewer management-determined actions would take three or more such actions.

Table 8

The actual effect of management-determined actions: Change in *Salmonella* share based on the number of management-determined actions taken [1]

Industry	Number of management-determined actions					Mean	Maximum management-determined actions effect
	1	2	3	4	5		
	Percent change						
Cattle carcass	132.2	200.1	284.0	352.0	n.a.	239.6	396.5
Ground beef	9.8	16.9	23.4	n.a.	n.a.	14.7	37.7
Hog carcass	22.6	36.8	55.0	61.6	66.2	38.6	66.2
Broilers	4.3	8.5	12.5	15.4	n.a.	10.3	17.0
Mean management-determined actions (excludes cattle)[2]	12.8	21.3	28.1	26.3	66.2	20.4	40.3

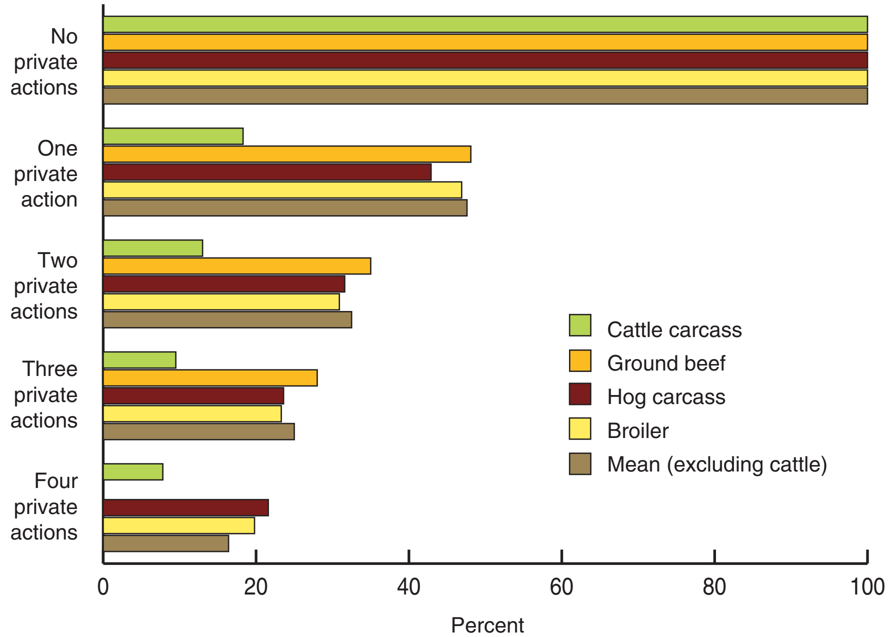
n.a. = Not applicable.

[1] The actual management-determined actions effect only includes contributions from management-determined actions taken by a plant. Some plants in the same industry may take three actions while others take only one, suggesting that the actual impact of management-determined actions varies from plant to plant and is less than the maximum amount. For example, the share of hog carcasses testing positive for *Salmonella* spp. changed 36.8 percent when taking two management-determined actions but changed 61.6 percent when taking four actions. If no actions are taken, then the contribution due to management-determined actions is zero percent and, for process regulation, it is 100 percent.

[2] We do not include cattle slaughter in the mean value because it is an outlier in discussions of absolute effects. We include it otherwise because relative effects are meaningful and cattle slaughter is a very important industry.

Source: Economic Research Service estimates.

Figure 7
Mean share of *Salmonella* reduction due to process regulations in four meat and poultry industries, by number of management-determined actions



Notes:

1. A maximum of five management-determined actions have statistically significant effects (table 6), but most plants do not take all actions, giving process regulation a bigger role in food safety process control than suggested in figures 2-6. Table 3 shows that 15 plants took no actions, 79 took only one action, and 120, 109, 32, and 1 plant took 2, 3, 4, or 5 actions, respectively.
2. Shares given above show the actual share of *Salmonella* spp. reduction due to process regulation. It equals one minus the actual share of *Salmonella* spp. reduction due to management-determined actions. This actual share equals the average for all plants with a given number of management-determined actions (e.g., two actions). The management-determined actions could be any of the six management-determined actions and differ from plant to plant: For example, one plant may take one management-determined action, such as a buyer contract, while another may also take one action, such as vertical integration. Each plant would have one action, but each plant would also have different shares of management-determined actions because different management-determined actions yield different amounts of *Salmonella* reduction.
3. The actual share of *Salmonella* spp. reduction due to management-determined actions = (actual management-determined effects)/(actual management-determined effects + regulatory effects), where actual management-determined effects for a given number of private actions comes from table 8 and regulatory effects comes from the top panel of table 7. For example, the actual management-determined effect for a cattle slaughter plant with one action is 132.2 percent (table 8, second column for cattle slaughter). Regulatory effects is 29.8 percent (table 7, third column of the table and top panel), does not change with the number of management-determined actions. Thus, the actual share of *Salmonella* spp. reduction due to management-determined actions equals 81.6 percent and the share of *Salmonella* spp. reduction due to process regulation is 18.4 percent.

Source: Economic Research Service estimates.

Conclusion

This paper empirically examines how market incentives affect the ability of meat and poultry plants to control the prevalence of *Salmonella* spp. occurring in meat and poultry products. Using management-determined actions as a measure of those incentives, the report examines the impact of process regulations and management-determined actions on the share of samples testing positive for *Salmonella* spp. in an FSIS testing program. It is estimated that management-determined actions actually taken (not all managers take all actions) account for about two-thirds and process regulations about one-third of reductions in *Salmonella* spp. in meat and poultry. We also found that the importance of process regulation varies across plants, accounting for 50 percent or more of all food safety process control for about a quarter of the plants and for the entire food safety process control system of some plants.

The results demonstrate that both process regulation and management-determined actions play vital roles in meat and poultry food safety process control, and that meat and poultry food safety process regulation is a floor that some plants use as their only means of food safety process control, while the majority of plants use it as a basis for building a more sophisticated food safety process control system.

This report also illustrates a variety of ways to enhance food safety process control. Given this variety, the most successful strategy for controlling pathogens may be to devote effort across a range of practices and technologies. Focus on a single type of control may yield some gains, but leave many other avenues unexploited.

Results suggest that management-determined actions make a substantially greater contribution to meat and poultry food safety process control than process regulation for most plants. For example, high capital expenditures and improved organizational arrangements each had twice the impact as process regulation did. Since health benefits data were not available, it was not possible to evaluate the costs of these management-determined actions relative to the public health benefits.

Specific food safety processing technologies provide few advantages in terms of *Salmonella* spp. reduction. Only the use of steam vacuum units in hog carcass plants generated lower *Salmonella* shares. Combinations of specialized equipment and practices did affect *Salmonella* shares in cattle carcass plants and broilers. *Salmonella* spp. reduction provided by those technologies, however, was still less than *Salmonella* spp. reduction achieved through increases in employee actions, high capital expenditures, or organizational arrangements.

Questions remain about whether management-determined actions are motivated by market forces or compliance with performance standards. The case that market forces have a strong influence on management-determined actions is quite clear, however. Market forces are driven by fears of losing a brand image, a reputation for quality products, or a major customer because of inadequate food safety process control. The effects of losing a reputation for food safety due to product recalls are well documented (Thomsen and McKenzie, 2001). Additionally, the response of the broiler industry to adverse media coverage indicates the effectiveness of market forces (Waldroup, 1992). Finally, anecdotal evidence suggests that many plants suffering large meat or poultry product recalls also increased their investments (Kenneth B. Moll & Associates, 1999) or, as in the cases of Hudson Meats and the Topps Meat Company, were forced to exit their industries.

There is little evidence showing the extent to which performance standards affect management-determined actions. For example, no documented reports have indicated that plants bought food safety processing equipment or took any other management-determined action to comply with the *Salmonella* spp. or generic *E. coli* performance standards. Plant managers probably were not thinking about performance standards when they entered buyer contracts because these arrangements are strictly between buyers and sellers. Performance standards leading to high capital expenditures (as used in this report) are also not likely because the ERS survey question upon which it is based asked the respondent whether plant managers had made capital investment beyond those required to comply with the PR/HACCP rule.

Government policies affect management-determined actions in more ways than through performance standards. Food safety information provided by Government officials plays an important role in shaping consumer and buyer demands. FSIS enforces zero tolerance rules for two human pathogens—*Listeria monocytogenes* and *E. coli* O157: H7—and a less strict standard for *Salmonella* spp. by testing products in the marketplace. State agencies test some products in the marketplace, and public health experts isolate victims of foodborne illnesses and trace the pathogens to the source. If State agencies or other sources find that products in the marketplace are contaminated, then FSIS has the power, credibility, and obligation to warn consumers about the potentially harmful food product and recall products. Warnings about product safety take place via public health announcements that both warn consumers about potentially harmful products and adversely affect a firm's reputation for food safety. Economists have shown that a loss of reputation negatively affects profitability and encourages managers to take actions to enhance food safety process control.

FSIS could further encourage market forces and increase management-determined actions by increasing product testing in the marketplace and providing consumers and buyers with more information about the meat and poultry food safety quality of particular plants and firms. FSIS has recently begun publishing accounts of plant performance on *Salmonella* spp. tests and noncompliance reports with SSOPs and HACCP plans. These are positive activities that give consumers, consumer advocate groups, and others information about plant food safety process controls and should encourage greater food safety investments by meat and poultry producers.

Limitations and Further Research

Four limitations to this study may drive future research:

- The available *Salmonella* spp. test results did not give a complete picture of meat and poultry food safety for the entire industry because not all plants were sampled.
- *Salmonella* spp. is only one of many harmful pathogens, and current data may give an incomplete picture of meat and poultry food safety.
- The analysis could not precisely determine whether management-determined actions were driven by performance standards or market effects, making it difficult to assess the contributions of performance standards to *Salmonella* spp. control.
- The ERS survey and the final dataset were not nationally representative, so results cannot theoretically be generalized.[26]

The initial data were collected in 2001, but further study with more current data may show how improvements have progressed.

[26] As discussed earlier, the bias may have been minimal since the share of total output of respondents closely tracks the share of plants that participated in the survey. Plant size and survey response were not correlated, and the data were treated with a post-stratification adjustment (Gelman and Carlin, 2002).

References

Balsevich, Fernando, Julio A. Berdegue, Luis Flores, Denise Mainville, and Thomas Reardon. "Supermarkets and Produce Quality and Safety Standards in Latin America," *American Journal of Agricultural Economics* 85 (5, 2003): 1147-1154.

Bolton, D.J., A.H. Oser, G.J. Cocoma, S.A. Palumbo, and A.J. Miller. "Integrating HACCP & TQM Reduces Pork Carcass Contamination," *Food Technology* 53(4, 1999): 40-43.

Coglianese, Gary, and David Lazer. "Management-Based Regulation: Prescribing Private Management to Achieve Public Goals," Working Paper (02-11), AEI-Brookings Joint Center for Regulatory Studies, 2002.

Colatore, C., and J.A. Caswell. "The Cost of HACCP Implementation in the Seafood Industry: Case Study of Breaded Fish," *The Economics of HACCP—Costs and Benefits*, L.J. Unnevehr (Ed.), pp. 45-68, St. Paul, MN: Eagan Press, 2000.

Gelman, Andrew, and John B. Carlin. "Poststratification and Weighting Adjustments," *Survey Nonresponse*, Robert M. Groves, Don A. Dillman, John L. Eltinge, and Roderick J. A. Little, (Eds.), pp. 289-302, New York, NY: John Wiley & Sons, Inc., 2002.

Golan, Elise, Tanya Roberts, Elisabete Salay, Julie Caswell, Michael Ollinger, and Danna Moore. *Food Safety Innovation in the United States: Evidence from the Meat Industry*, Agricultural Economic Report No. 831, U.S. Department of Agriculture, Economic Research Service, 2004.

Greene, William H. *Econometric Analysis,* New York: MacMillan Publishing, 1993.

Haavelan, A.H., M.J. Nauta, and J.T. Jansen. "Fine-tuning Food Safety Objectives and Risk Assessment," *International J. Food Microbiology* 93, 11(2004): 11-29.

Henson, Spencer, Ann-Marie Brouder, and Winnie Mitullah. "Food Safety Requirements and Food Exports from Developing Countries: The Case of Fish Exports from Kenya to the European Union," *American Journal of Agricultural Economics* 82 (5, 2000): 1159-1169.

Henson, Spencer, and James Northen. "Economic Determinants of Food Safety Controls in Supply of Retailer Own-Branded Products in United Kingdom," *Agribusiness* 14 (March-April, 1998): 113-26.

Jaffee, Steve, and Oliver Masakure. "Strategic Use of Private Standards to Enhance International Competitiveness: Vegetable Exports from Kenya and Elsewhere," *Food Policy* 30(June, 2005): 316-33.

Kenneth B. Moll & Associates. *Sara Lee Class Action*, 1999, http://Kbmoll.com/.

Klein, Benjamin, and Keith B. Leffler. "The Role of Market Forces in Assuring Contractual Performance," *Journal of Political Economy* 89 (1981): 615-41.

Marsh, Thomas L., Ted C. Schroeder, and James Mintert. "Impacts of Meat Product Recalls on Consumer Demand in the U.S.A.," *Applied Economics* 36 (May, 2004): 897-909.

Ollinger, Michael, Danna Moore, and Ram Chandran. *Meat and Poultry Plants' Food Safety Investments: Survey Findings,* Technical Bulletin 1911, U.S. Department of Agriculture, Economic Research Service, 2004.

Ollinger, Michael, and Valerie Mueller. *Managing for Safer Food: The Economics of Sanitation and Process Controls in Meat and Poultry Plants,* Agricultural Economic Report No. 817, U.S. Department of Agriculture, Economic Research Service, 2003.

Önal, H., L.J. Unnevehr, and A. Bekric. "Regional Shifts in Pork Production: Implications of Competition and Food Safety," *American Journal of Agricultural Economics* 82:968-978, 2000.

Piggot, Nicolas E., and Thomas L. Marsh. "Does Food Safety Information Impact U.S. Meat Demand?" *American Journal of Agricultural Economics* 86 (February, 2004): 154-74.

Reimer, Jeffrey J. "Vertical Integration in the Pork Industry," *American Journal of Agricultural Economics* 88(February, 2006): 234-48.

Starbird, Andrew. "Supply Chain Contracts and Food Safety," *Choices,* second quarter, pp. 123-28, 2005.

Thomsen, Michael R., and Andrew M. McKenzie. "Market Incentives for Safe Foods: An Examination of Shareholder Losses from Meat and Poultry Recalls," *American Journal of Agricultural Economics* 82(3) (2001): 526-38.

Thomsen, M.R., R. Shiptsova, and S. J. Hamm. "Sales Responses to Recalls for *Listeria monocytogenes*: Evidence from Branded Ready-to-Eat-Meats," *Journal of Agricultural Economics* 28 (2000): 482-93.

Tobin, James. "Estimation of Relationships for Limited Dependent Variables," *Econometrica* 26 (1958): 24-36.

Umholtz, Robert. Personal communication on June 21, 2000.

U.S. Department of Agriculture, Economic Research Service. *Food Safety Technologies and HACCP Compliance Survey of Meat and Poultry Plants, 2000,* U.S. Department of Agriculture, Economic Research Service, 2002.

U.S. Department of Agriculture, Food Safety and Inspection Service. *Enhanced Facilities Database, 2001,* U.S. Department of Agriculture, Food Safety and Inspection Service, 2001.

U.S. Department of Agriculture, Food Safety and Inspection Service. *PBIS Database, 1998-2003,* U.S. Department of Agriculture, Food Safety and Inspection Service, 2004.

U.S. Department of Agriculture, Food Safety and Inspection Service. *Salmonella Test Results, 1998-2003,* U.S. Department of Agriculture, Food Safety and Inspection Service, 2004.

U.S. Department of Agriculture, Food Safety and Inspection Service. *Progress Report on Salmonella Testing of Raw Meat and Poultry Products, 1998-2004,* U.S. Department of Agriculture, Food Safety and Inspection Service, 2005, www.fsis.usda.gov/science/Progress_Report_*Salmonella*_Testing_1998-2004/.

U.S. Department of Agriculture, Food Safety and Inspection Service. *Salmonella Database, 1998-2003,* U.S. Department of Agriculture, Food Safety and Inspection Service, ongoing.

Waldroup, Amy L., Bruce M. Rathberger, Richard Forsythe, and Les Smoot. "Effects of Six Modifications on the Incidence and Levels of Spoilage and Pathogenic Organisms on Commercially Processed Postchill Broilers," *Journal of Applied Poultry Research* (1992) pp. 226-234.

Williamson, O. *The Economic Institutions of Capitalism,* New York: The Free Press, 1985.

Appendix A: Linking Food Safety to Management-Determined Actions and Process Regulations

Meat and poultry food safety is just one product attribute among many, including marbling, taste, fat content, etc. Some of these product attributes may be mutually dependent and must be examined jointly. For example, marbling may make meat tender, but may also increase fat content, suggesting that tenderness and fat must be examined jointly. Attributes such as harmful pathogens, however, are separable because pathogens thrive in all types of meat products. This separability of harmful pathogens means that food safety can be examined separately from other attributes.

Equation 1 is a production function in which meat and poultry plants produce food safety (S) with inputs that include the discretionary labor needed to meet demands for meat and poultry food safety (L), physical and human capital (**K**), technology (**t**) and a vector of control variables (**X**) that accounts for differences in seasonality, location, and other factors that can affect food safety.

Equation 1: $S = f(L, \mathbf{K}, \mathbf{t}, \mathbf{X})$

Technology includes any method, equipment, or other means used to produce food safety. For our case, these are food safety process regulations (**R**), innovative food processing technologies devoted to meat and poultry food safety ($\boldsymbol{\tau}$), organizational innovations (**O**), and plant technology (**P**). Process regulations specify cleaning practices and monitoring activities, organizational innovations enhance management's ability to control food safety, and plant technology refers to plant size and scope. Control variables include seasonality, location, etc. All of these variables are discussed in detail in the text and expressed in equation 2.

Equation 2: $S = f(\mathbf{R}, L, \mathbf{K}, \boldsymbol{\tau}, \mathbf{O}, \mathbf{P}, \mathbf{X})$

Equation 2 was used to develop an empirical model (Appendix B) and includes two types of variables: process regulations and management-determined actions. Process regulations are sanitation and process control tasks; management-determined actions are investments in physical and human capital, food safety technology, and organizational arrangements.

Appendix B: Empirical Modeling

An empirical model is needed to examine the impact of the factors affecting food safety, as described in equation 2 of Appendix A. The variable S is defined as the share of samples testing positive for *Salmonella* spp. It is bounded below by zero (plants with no positive test samples) and bounded above by one (plants with only positive test samples). In practice, many plants had some positive samples, but no plant had only positive ones, making the distribution bounded from below but not from above (table 2).

Since most plants have none or very few samples testing positive for *Salmonella* spp., it is assumed that S has a normal distribution centered around and truncated at zero, meaning that, if it were possible, some values would be less than zero.[1] Managers at plants with samples that fall in this truncated region are concerned about ensuring meat and poultry food safety.

[1] Table 2 shows that about 40 percent of all observations have zero values and only about 2 percent have values that exceed 30 percent. This type of distribution forms half of a typical bell-shaped distribution as assumed in the empirical model.

It may seem that S should be modeled as a proportion. Two problems emerge, however, by doing so. First, Greene points out that the estimation breaks down if any of the proportions are zero or one. Table 2 shows that there are many observations with zero proportions. Second, a wide variety of proportions are possible since FSIS ceases testing if a plant exceeds its tolerance level for samples testing positive for *Salmonella* spp. For example, if a tolerance is 5 samples out of 50, then it will stop testing after 5 samples if the first 5 samples test positive for *Salmonella* spp. Similarly, FSIS stops testing once a plant reaches a point at which it is impossible for it to fail the test set. For example, FSIS stops testing after 45 samples test negative for *Salmonella* spp. if it was allowed 5 positive samples and the test set consists of 50 samples. Similarly, it would stop testing after 46 samples if only one sample tests positive.

A more appropriate regression approach is a Tobit model since it allows for a continuous, censored dependent variable that is truncated at zero. Tobin (1958) was the first to consider regressions with censored dependent variables, like S, making his econometric method particularly well-suited for our analysis. Using a tobit regression, as given by Greene (1993), we specify the following model:

$$S_i = \beta_1 No\_SSOP\_noncompliances_i + \beta_2 No\_FC\_noncompliances_i +$$

$$\beta_3 HACCP\_noncompliance\_share_i + \beta_4 labor\_share\_comprised\_of\_FS\_workers_i +$$

$$\beta_5 Employee\_actionsi + \beta_6 High\_capital\_expenditures_i + \beta_7 Change\_plant\_layout_i +$$

$$\beta_8 FS\_processing\_technology_i + \beta_9 Vertical\_integrationi + \beta_{10} Supplier\_contract_i +$$

$$\beta_{11} Buyer\_contract_i + \beta_{12} Sizei + \beta_{13} Multi\_process_i + \beta_{14} Share\_samples\_quarter1_i +$$

$$\beta_{15} Share\_samples\_quarter3_i + \beta_{16} Prior\_Salmonella\_testing_i + \beta_{17} Year\_of\_testing_i +$$

$$\beta_{18} Western\_location_i + \beta_{19} Western\_corn\_location_i + \beta_{20} Cow\_bull\_plant + \varepsilon_i$$

The independent variables are components of the vectors given in equation 2 in Appendix A. Definitions are given in table 4. We include only the label in the table since the label and the variable name are nearly identical. The middle column of table 4 shows the vector from equation 2 to which the label corresponds. For example, the regulatory vector, **R**, in equation 2 is comprised of three regulatory variables:

- No_SSOP_noncompliances.
- No_FC_noncompliances.
- HACCP_noncompliance_share.

Appendix C

Change in *Salmonella* shares if all plants take all management-determined actions[1]

Source of impact	Variables	Cattle	Ground beef	Hog carcass	Broilers	Mean[2] (no cattle)
				Salmonella *share*		
Process regulation	No SSOP noncompliances + no FC noncompliances	2.7	4.1	20.4	1.9	8.8
	HACCP noncompliance share	4.3	15.4	0.0	16.4	10.6
Total process regulation		7.0	19.5	20.4	18.3	19.4
Management-determined actions						
Capital	Employee actions	31.0	0.0	19.2	7.2	8.8
Human capital	High capital expenditures + change plant layout	12.7	16.9	0.0	36.1	17.7
Physical capital						
Sum of capital		43.7	16.9	19.2	43.3	26.5
Process technology	Food safety processing technology[3]	10.4	16.2	2.9	4.3	7.8
Sum of process technology		10.4	16.2	2.9	4.3	7.8
Organization						
Vertical integration	Vertical integration[4]	16.9	16.2	14.5	0.0	10.2
Contracts with suppliers	Supplier contract	0.0	7.9	1.7	12.0	7.2
Contracts with buyers	Buyer contract	22.0	23.3	41.3	22.1	28.9
Sum of organization		38.9	47.4	57.5	34.1	46.3
Share of all management-determined actions		93.0	80.5	79.6	81.7	80.6
Maximum effect—all factors		100	100	100	100	100

[1] Values come from table 7 and are put in terms of percentages. It is assumed that each plant takes all management-determined actions. Actual percent shares of total *Salmonella* reductions are shown in figure 7 and are based on the management-determined actions actually taken (i.e., they adjust *Salmonella* performance).
[2] Mean values are based on ground beef, hogs, and chicken. Cattle slaughter is excluded from mean calculations because it gives too much influence over the mean values.
[3] Food safety processing technology is a hide removal index valued between zero and one for cattle slaughter, an equipment index valued between zero and one for ground beef and dummy variables equal to one if a hog carcass plants uses steam vacuum units, or a broiler plants uses seven types of modern chicken slaughter equipment and zero otherwise.
[4] Vertical integration means cattle carcass plants that grind meat, ground meat plants that slaughter animals, and hog carcass and chicken broiler plants that further process meat.