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Food Safety Audits, Plant Characteristics, and Food Safety Technology Use in Meat and Poultry Plants

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Abstract

Food safety technology can increase a company's capacity to prevent a foodborne contamination. A food safety audit—a quality control tool in which an auditor observes whether a plant's processing practices and technologies are compatible with good food safety practices—can indicate how effectively food safety technology is being used. Fast food restaurants, grocery stores, and other major customers of meat and poultry processing plants conduct their own audits or hire auditors to assess the soundness of a plant's processing operation. Meat and poultry plants can also audit themselves as a way to help maintain process control. In this report, we document the extent of food safety audits in meat and poultry processing plants. We also examine the associations between the use of audits and plant size, firm structure, and food safety technology use. Results show that larger plants, plants subject to food safety audits, and plants that are part of a multiplant firm use more food safety technology than other plants. Plants subject to both plant-hired and customer-hired audits had greater technology use than single (plant- or customer-hired) audit plants.

Keywords: Meat and poultry processing, safety standards, product recalls, food safety technology, food safety audits

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Summary

What Is the Issue?

Food contamination poses serious threats to human health as well as to the economic viability of meat and poultry plants. Food safety technology can increase a company's capacity to prevent a foodborne contamination. A food safety audit—a quality control tool in which an auditor observes whether a plant's processing practices and technologies are compatible with good food safety practices—can indicate how effectively food safety technology is being used. Fast food restaurants, grocery stores, and other major customers of meat and poultry processing plants conduct their own audits or hire auditors to assess the soundness of a plant's processing operation. Meat and poultry plants also can audit themselves as a way to help maintain process control and as a marketing tool. In this report, we document the extent of food safety audits in U.S. meat and poultry processing plants and examine the association between the use of audits and plant size, firm structure, and food safety technology use.

What Were the Study Findings?

- In the poultry slaughter, cattle slaughter, and ready-to-eat products (e.g., luncheon meats) industries, at least 90 percent of output is from audited plants.
- In the hog slaughter, ground beef, and not-ready-to-eat products (e.g., meat cuts) industries, at least 70 percent of output is from audited plants.
- More than one-half of all plants were audited in the poultry slaughter industry. About one out of three cattle slaughter and hog slaughter plants were audited.
- Plants with customer-hired or plant-hired auditors use significantly higher levels of food safety technology than plants without auditors. The most notable differences between plants using auditors and those not using auditors were in the use of testing and equipment technologies, and the smallest differences were observed in sanitation practices. These results hold within plant size categories.
- The use of double audits may indicate firms with the strongest incentives to maintain food safety. Double-audit plants—those using both plant-hired and customer-hired auditors—use greater food safety technology than plants using only one audit type (either plant-hired or customer-hired). These results hold after controlling for plant size.
- Larger plants and plants owned by multiplant firms are associated with a significantly higher level of food safety technology use across all industries that were examined.

How Was the Study Conducted?

Food safety technology use in six categories of meat and poultry plants—cattle, hog, and poultry slaughter; ready-to-eat (e.g., luncheon meats); not-ready-to-eat (e.g., meat cuts); and ground beef—is examined using a technology index developed by Ollinger, Moore, and Chandran (2004) and

using Tukey-Kramer comparison tests and other statistical tools. Six technologies were examined: hide removal (dehiding), sanitation, operations, equipment, testing, and an overall measure. The data on the use of food safety technologies are nationally representative and include information on 600 slaughter plants and 700 processing-only meat and poultry plants collected by RTI International for USDA's Food Safety Inspection Service in 2004 and 2005. They are the most recent data available.

Introduction

Food safety audits provide information about the efficacy of a plant's food safety process control system at some point in time and are becoming increasingly important to the meat and poultry industry.[1] Fast food restaurants, grocery stores, and other major customers of meat and poultry plants use audits to assess the soundness of a plant's processing operation and often require audits as conditions for granting a plant their business. Meat and poultry plants use audits as a way to help maintain process control and also as a marketing tool that could be useful for winning more business (Richard, 2003). By 2005, the use of auditors had become widespread. Some recent food safety incidents, however, have called into the question the usefulness of audits. Moss and Martin (2009) and Harris (2010) reported that several recently audited plants had recalled millions of dollars worth of peanut, meat, egg, and other products.

The 1993 outbreak of *E. coli* O157:H7 in hamburgers served at Jack-in-the-Box restaurants led to a loss in net income for the restaurant company of around $160 million over the 18 months following the outbreak (Roberts et al., 1997). In response, Jack-in-the-Box imposed strict food safety standards on its suppliers and became a leader in the provision of food safety (Golan et al., 2004). Other restaurant chains, grocery stores, food manufacturers, and other buyers also recognized the threat that an adverse food safety event could pose to their business. Thus, they developed their own food safety process control programs and hired food safety auditors to evaluate their effectiveness.

Audits may complement food safety technology. While the amount of investment in food safety technology indicates a company's commitment to food safety and also its capacity to prevent foodborne contamination, food safety audits can indicate how effectively food safety technology is being used.

To date, there has been little research on the use of audits and their relationship with food safety technology in meat and poultry plants. Although the use of auditors does not necessarily cause plants to use more food safety technology or vice versa, an association may exist between the use of auditors and food safety technology, particularly if plants using auditors are the types of plants that make more extensive use of food safety investments or if the forces encouraging the use of food safety auditors encourage the use of food safety technologies. Our purpose in this paper is to (1) examine the extent of food safety audit use, (2) see whether the use of audits varies with plant size and across industries, and (3) evaluate whether the use of audits, plant size, and firm type are associated with food safety technology use.

Our analysis relies on data from a 2004-05 national survey of meat and poultry plants by RTI International for USDA's Food Safety Inspection Service (FSIS) on the use of food safety technologies. Altogether, nearly 400 meat slaughter, more than 200 poultry slaughter, and almost 700 processing-only plants responded to a survey that was sent to a nationally representative sample of plants. The survey covered an extensive array of food safety technologies. Some of these are more labor-intensive food safety tasks, such as sanitation practices, and others are fixed assets, such as steam vacuum

[1]The terminology surrounding food safety audits can be confusing. In the certification literature, a first-party audit is an audit performed within the meat or poultry plant by the plant itself; a second-party audit is an audit conducted by or on behalf of a purchasing organization, such as a grocery store chain or another meat or poultry plant; a third-party audit is undertaken by an independent certification body that certifies a process and has no ties to either the customer or the supplier. In the trade literature, a third-party auditor is often referred to as an auditor who is not an employee of the plant or customer. To avoid confusion, we do not use the first-, second-, and third-party audit terminology.

units. The survey also gathered information on plant characteristics, such as product inputs and outputs, plant size, and firm type.

We measure plant food safety technology using an index that is constructed from the food safety technology questions included in the RTI International survey. There is one comprehensive measure of all technologies and separate indexes for five technology types—hide removal (dehiding), sanitation, operating practices such as disposal of scrap products (operations), equipment, and testing. By using five specialized technology indexes that separate labor-intensive food safety activities, such as sanitation, from capital-intensive food safety measures, such as equipment, we can better understand how types of technologies vary with plant characteristics. Indexes were based on a more comprehensive assortment of food safety technologies than was available for Ollinger, Moore, and Chandran (2004).

We next discuss food safety audits and then provide an economic framework of how incentives provided by the private market (e.g., major customers) encourage food safety. After that, we discuss the survey methodology, describe the data in more detail, and present results of food safety expenditures and technological choices in the context of our model.

Types of Audits and Reasons for Using Them

Audits of manufacturing plants are a systematic documentation of the extent to which a plant meets specific standards established by the plant or a customer. There are many types of audits, but most fall into these categories: food safety and good manufacturing practices (GMPs), hazard analysis and critical control points (HACCP) verification (including benchmarking and confirming a program), animal welfare, good laboratory practices (GLPs), and quality systems. Auditors may also evaluate document management systems, pest control practices, water and hygiene controls, corrective and preventive procedures, purchasing and vendor practices, system calibrations, allergen controls, shipping and receiving procedures, education and training systems, and sanitation practices (Stier, 2009).

Audits indicate whether a plant is performing specified functions on a particular day. There is no guarantee that the plant will be performing the same way on other days, so it is important that audits be scheduled on a frequent but random basis. If the auditor comes at a predictable time, there is an incentive for plant management to prepare for an audit.

Audits cover a prescribed set of activities or processes. Plants receive a favorable rating if they meet those standards. A favorable rating does not mean that a plant produces safe food. A plant could be producing contaminated products, yet it could receive a good rating from its auditor. For example, if the auditor was only obligated to evaluate employee sanitation and the auditor determined that employees properly washed their hands, then the plant would earn a good rating even if the plant was producing contaminated products. Cases like this have occurred. Michael Moss and Andrew Martin (2009) indicated that Peanut Corporation of America produced Salmonella-contaminated peanuts for many months even though the plant received superior auditing scores from AIB International, an auditing company. Lena Sun (2010) reported that Wright County Farms received a superior rating from AIB shortly before its eggs sickened more than 1,800 people. Since the AIB auditors of these establishments did no product testing, the auditors could not evaluate product food safety, and, since the establishments satisfactorily performed activities needed to pass their audits, they received superior grades.

Audit standards vary. Robert Brackett, former senior vice president of the Grocery Manufacturers Association, asserted that some inspections can be rigorous, particularly if they use internationally recognized private benchmarks (Sun, 2010). However, those audits are expensive and therefore not commonly done in the majority of U.S. meat and poultry plants.

The effectiveness in improving food safety after an audit depends on the seriousness with which a plant takes the auditor's recommendations. Plant managers likely will implement an auditor's recommendations if not following the recommendations poses a risk to their business, such as losing a potential contract. However, if a customer does not evaluate audit outcomes carefully and does not require a plant to make changes, then recommendations may or may not be followed. The Peanut Corporation of America apparently did not implement several important recommendations made by

auditors because the peanut processing plant's customers failed to follow up on those recommendations by their own auditors (Moss and Martin, 2009).

Auditor Services and the Incentives To Use Them

Large fast food restaurants, grocery store chains, and other large customers of meat and poultry plants have recognized that they face considerable market risks if they serve contaminated meat and poultry products. These threats have led some large customers to demand strong food safety measures from their meat and poultry suppliers. A meat or poultry plant, on the other hand, wants to reduce its costs as much as possible, so it has an incentive to conduct only the minimum level of sanitation and process control. Since these two interests are at odds, the plant and its large customer may enter into a long-term contract in which the plant agrees to perform specified food safety tasks in exchange for an exclusive production agreement or a price premium for its products. (Ollinger and Mueller, 2003; Golan et al., 2004).

A long-term contract does not completely resolve the conflict because the activities of plants are not observed by their customers. Customers cannot distinguish between contaminated meat and poultry and wholesome meat or poultry when there is no outward sign of contamination such as an "off" smell or discoloration. As a result, major customers must either risk receiving contaminated meat or evaluate the food safety performance of their suppliers. If they choose to evaluate food safety performance, large customers can use their own inhouse experts or hire meat and poultry food safety auditors. The frequency of the evaluations depends on the interests of the large customer.

Auditor services may be used in other situations as well. For example, a plant manager may use an auditor to assess the food safety integrity of the plant's operations. Below, we discuss four types of auditing arrangements.

Types of Audits and Their Incentives

There are four types of auditing arrangements that a plant may have:[2]

1. First, a plant may be subject to no audits. These plants likely serve customers who do not demand audits and have managers who see no need for audits. A manager may not use auditor services because audits are costly and (1) a plant may be small enough that the manager can closely monitor operations or (2) the plant may never have had an adverse food safety event and the manager may see no need to change, or (3) the manager may not view food safety as a top priority.
2. The second auditing arrangement is when plants are subject to audits by customers. These customers want to be sure that the meat or poultry they buy is safe and that their meat or poultry suppliers are meeting the food safety standards that they agreed to as part of a purchase contract. In this case, the auditor acts as an agent of the meat or poultry customer. Since the customer hires and pays the auditor, the incentives between the meat or poultry customer and auditor are aligned and the auditor has a strong incentive to report any deviations by a plant that are below the standards of the customer.

[2]One might consider a different type of audit in which auditors hired by a plant evaluate the performance of cleaning crews hired as contractors by that plant. Presumably, respondents to the survey would indicate whether the auditor was hired by the customer or the plant and report accordingly. It should also be noted that USDA-FSIS and USDA's Agricultural Marketing Service (AMS) periodically conduct audits as part of their regulatory authority. Since these are not initiated by the private sector, they are neither reported nor discussed here.

3. A third type of audit relationship is when a large meat or poultry customer wants an audit but leaves it up to the plant to select the auditor. Here plant management is an agent of the customer and the auditor is an agent of the plant management. This type of relationship is complicated because plant management hires the auditor. The plant could hire an experienced auditor that gives a fair assessment or it could hire a low-skilled or less experienced auditor who is less able to identify deviations from expected performance and is more likely to give a good report. Regardless of which type of auditor is hired, an auditor should report all observed deviations from generally accepted food safety practices. However, this could create a conflict for the auditor because a negative report would look bad for the plant that hired the auditor and could cause the plant to deny the auditor any future business. Thus, the decision for the auditor is to weigh any benefits that may be achieved from giving a report that is more favorable to the plant against the costs of losing a good reputation for auditing services.

4. A fourth type of auditing arrangement is when plants hire their own auditors. The plant could use the audit results to verify the effectiveness of components of its manufacturing process or its entire processing system. In this case, a plant would ask an auditor to review all or some of its food safety activities and could adjust all, some, or none of the processes that an auditor cites as being deficient. Thus, a plant could have an audit and the audit could indicate that food safety activities that the auditor examined met specified standards. Yet, a plant could have poor food safety performance because activities not evaluated by the auditor caused a system failure.

Plant managers have the option to comply with audit findings and do so only if it is profitable. Given similar findings, managers would be more likely to comply with audits as the costs of compliance drop, the value of the customer's purchase order rises, and the threat of a detectable food safety failure rises.[3] For example, a plant would likely comply with the auditor's findings if the customer has a large order and the cost of complying with the audit report is low. It would also likely comply if an audit reveals a serious food safety breach that could undermine the viability of a plant's business. However, if a customer has a small order and the costs of complying with the audit are high, then a plant manager might not strictly comply with the auditor's findings.

[3]Compliance costs are afffected by the strictness with which a customer may hold plants to the audit findings. If plants must strictly adhere to findings, then costs rise. If plants do not have to strictly meet audit requirements, then costs drop.

Audit Compliance and Audit Certification

Customers and plants recognize the incentives existing in auditor-client relationships. Yet, no government or third party guarantees that a plant adhered to the recommendations put forward by the auditor. Rather, it is up to the buyer to verify that auditor recommendations were followed. For buyers purchasing large quantities of few inputs from a limited number of plants, using auditor services and verifying their effectiveness may be relatively low cost. But, some buyers may purchase thousands of inputs or buy a few inputs from a large number of plants, making it very costly to verify that auditor recommendations were followed.

There is also no government or third-party agent that attests to the quality of the auditor. Thus, certifications have become a particularly important

device for attesting to auditor skill. But, there are many certifications available, and their quality may depend on the quality and reputation of the certifiers (Sun, 2010). Certifiers that are well-recognized professionals in their field or organizations, such as the Professional Animal Auditor Certification Organization, Inc., may offer greater assurance of auditor quality than less well-known certifiers.

Large auditing firms and those with years of experience also can provide some reassurance about auditor quality because their reputations can be evaluated. According to Kyle Yudis, an executive with Silliker, Inc., a large international audit company, there are only about six large, international food auditing companies and hundreds of small food auditing companies (Yudis, 2010). The larger companies may serve a range of customer needs, while the smaller companies tend to specialize in just one industry or one type of audit.[4] The larger auditing companies may employ their own auditors or use contractors.

Number of Audits and the Incentives for Food Safety

It may be difficult to distinguish the food safety performance of plants audited by customer-hired auditors from the performance of plants audited by plant-hired auditors. Both have a single-type of audit arrangement, and, under these single-audit arrangements, there is one party to the exchange that may not put a strong emphasis on food safety. Plants subject to audits by customer-hired auditors but not by their own plant-hired auditor have customers who place some value on food safety. If the plant chooses not to have its own auditors, that suggests it sees no need for additional audit recommendations and verifications. Plants using only a plant-hired auditor appear to be concerned about food safety or they wouldn't have hired auditors. But their customers do not demand these audits and, thus, would not likely encourage a plant to select a high-quality auditor and follow all audit recommendations.

Double-audit plants (customer- and plant-hired auditors) likely have the strongest incentives to maintain food safety. These plants could have particularly cautious managers who hire auditors to inspect their operations in order to ensure that their plants comply with their customers' standards. Or, double-audit plants could have buyers who require them to be audited by particular auditors. Managers of double-audit plants may hire auditors to evaluate aspects of their operations not adequately addressed by their customers' audits. Or, an audit may be used to determine whether a plant's procedures meet acceptable standards. Regardless of the explanation, it appears that double-audit plants may place a stronger emphasis on food safety than single-audit plants because both parties (customer and plant) invest in auditor services.

[4]According to Stier (2009), there are many types of food safety audits. These audits may cover all or only part of a plant's entire food safety quality control system. Some common food safety audits are: Food Safety and Good Management Practices (GMPs) for Food Processing Facilities; Food Safety and GMPs for Distribution Centers; HACCP Verification Audit (benchmarking and confirming a program); Animal Welfare Audit; Good Laboratory Practices Audit; Quality Systems Audit; and Safe Quality Food (SQF) Audit. All of these programs as well as auditors have to have special types of certifications, depending on the type of food audited and the type of audit performed.

Economic Framework

Plants pay for auditor services, perform cleaning and sanitation tasks, monitor plant operations, conduct product testing, and make capital investments in food safety equipment in order to enhance food safety. These investments have cost the meat and poultry industry millions of dollars (Ollinger, Moore, and Chandran, 2004). Yet, there is no evidence that consumers are willing to pay a higher price for food safety (i.e., for guarantees that meat or poultry has less risk of harmful pathogens). Li and Hooker (2009) found that firms have rarely advertised that a product was free of pathogens and that there was no significant difference in price for firms that did advertise. Below, we examine why it may still be profitable for firms to invest in food safety.

Why Plants Make Food Safety Investments and Use Auditor Services

There are several factors motivating food safety investment. First, fear of lost profitability and revenues due to product recalls may encourage firms to use food safety technologies. Thomsen and McKenzie (2001) found that that firms that recalled contaminated meat or poultry products suffered a decline in long-run profitability. Piggott and Marsh (2004) and Marsh, Schroeder, and Mintert (2004) determined that adverse 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. Finally, McKenzie and Thomsen (2001) found that recalls for *E. coli* O157:H7 resulted in a decline in prices for boneless beef.

Plants may also invest in food safety technology and audit services to support an important brand. Shapiro (1983) showed that plants selling branded products must support their brands with investments because their products are readily identified by consumers and they want to convey an image of high quality. Food safety investment is necessary to avoid brand destruction through a product recall. Sara Lee, for example, suffered a large recall of branded hot dogs and was able to regain profitability in its branded hot dog business only after more than $70 million of investment in food safety and marketing (Auerswald, 1999).

Plants selling generic products, in contrast to those selling branded products, sell products to buyers that resell or reprocess that product with identical products from other suppliers, such that the producer of any single product cannot be identified. Thus, the plant producing generic products may invest less in food safety technology than plants selling branded products. All plants must invest in food safety technology up to a point that will enable them to meet USDA/FSIS or State regulatory standards.[5]

Other factors encouraging food safety technology use by meat and poultry slaughter and processing plants are purchase specifications and the fear of lost business from fast food restaurants and other large customers. Compliance with purchase specifications often requires the use of an array of food safety technologies (Golan et al., 2004). Meat and poultry plants with contracts with large customers are always under a threat of a contract

[5]All meat or poultry plants must be inspected by either the Federal or State Government. Under the Code of Federal Regulations (9 CFR Parts 321, 332, and 381 [Docket No. FSIS-2008-0039] RIN 0583-AD37), select State-inspected establishments have the option to ship meat and poultry products, bearing an official USDA mark of inspection, across State lines if they comply with all Federal standards under the Federal Meat Inspection Act (FMIA) and the Poultry Products Inspection Act (PPIA). These establishments will receive inspection services from State inspection personnel that have been trained in FMIA and PPIA requirements. State-inspected plants not among this select group of plants are permitted to ship only within their States. All State inspection agencies must meet the same safety standards as these of federally inspected plants.

cancellation if a serious product recall occurs. Hudson Meat left the ground-meat business after Burger King, a major customer, cancelled its contract following a major recall of Hudson products (Winter, 2002). Likewise, Topps Meat and Westland-Hallmark Meat companies also exited the beef industry after their products were subjected to recalls.

Plant Size and Firm Type, Food Safety Investment, and the Use of Auditors

The threat of business losses due to product recalls, the need to support branded products, and compliance with customer specifications encourage plants to make food safety investments and use auditor services. However, plants must still reach maximum profitability. Thus, they minimize their costs under the constraints of making the food safety investments and using the auditor services that their markets demand.

Food Safety Technology and Auditor Use and Plant Size

Cost minimizing behavior, different types of plant production technologies, and the food safety investments that plants must make to meet market demands suggests that plant-level food safety technology use may vary across plants. One determining factor in food safety technology use is the compatibility of a plant with different food safety technologies. Large plants using high-speed production lines must use high-speed food safety techniques to ensure that production lines operate continuously and produce meat and poultry that is free of harmful pathogens. Small cattle slaughter plants that butcher only a few animals per day may obtain the same level of food safety by closely monitoring operations and thoroughly cleaning plant facilities. Thus, small and large plants likely make different types and amounts of food safety investments.

Technological compatibility is important, but there are other reasons why larger plants may have a greater incentive to make food safety investments and use auditor services than smaller plants. First, large plants may have much greater cash flow and access to credit than small plants, and this greater access may enable them to purchase equipment more easily. Second, large plants have much more to lose in the event of a serious food safety failure. For example, assume that a plant can be sold for the value of its fixed investments, contracts, and goodwill and 50 percent of the value of firm is due to fixed investment and 50 percent is due to contracts and goodwill. Now suppose that there are two plants—one valued at $1 million and one valued at $1 billion—and that each loses its reputation for food safety. If the loss of a reputation for food safety causes all goodwill to vanish, then the smaller plant loses $500,000 and the larger plant loses $500 million. Thus, a large plant would be willing to invest more in food safety technology and auditor services than would a smaller plant.

Third, large plants may also have lower costs of using auditor services and some food safety technologies. Auditor services and carcass pasteurizing and other modern food safety equipment are expensive fixed costs, but large plants can spread theses fixed costs over more units of output than a small plant can, resulting in a lower cost per pound of output. For example, assume a large cattle slaughter plant processes 1 million pounds of meat per day

while a small plant processes 1 million pounds in a year, and that each plant chooses to pasteurize cattle carcasses with a steam pasteurizer costing $1 million in capital expenditures. If each plant must pay for equipment within 1 year, then the cost per pound for the large plant is less than one-half cent per pound while that for the small plant is about $1 per pound.[6] In addition, specialization of labor may enable large plants to gain more expertise about food safety technologies. This expertise may make them more prone to use food safety technologies than would a smaller plant.

Greater use of some food safety technologies and auditor services at large plants than at small plants does not mean that output from large plants therefore is safer. Small plants have an incentive to provide robust food safety if the markets they serve require it. Some small plants serve niche markets that link plants with products. By contrast, large plants with no pressure from customers and selling generic products on the spot market may feel little need to invest in food safety because their products may not be easily identified, especially once they have been reprocessed or labeled further down the supply chain.

Small plants realize their own advantages in maintaining food safety. Most importantly, they have more operational flexibility than do large plants. If a small plant has food safety problems, managers can slow production lines and address those problems with little lost production time. Moreover, sanitation and operations—two fundamental food safety technologies that all plants must maintain—tend to be scale-neutral (i.e., a plant with twice as much output as another plant may have to devote twice as much effort to sanitation and operations). Thus, smaller plants emphasizing sanitation in all their operations and maintaining constant vigilance over food safety process control may reach the same level of food safety as a large plant using complex food safety equipment.

A small plant may have less need for an auditor. Small plants are often managed directly by owners, who have a strong incentive to maintain food safety in order to avoid a loss of business as well as a blow to their personal reputations. Moreover, these plants have less complex operations, making them easier to monitor.

Single- and Multi-Plant Firms and Food Safety Investment

Firms that own more than one plant (multiplant firms) may be more likely to have audits and make food safety investments than single-plant firms. First, the expected losses at a multiplant firm may be higher than at a single-plant firm. Suppose, similar to a previous hypothetical example, 50 percent of the value of firm is due to fixed investment and 50 percent is due to contracts and goodwill. Now suppose that there are three plants producing the same product and each plant is valued at $100 million and that one firm owns two plants and the other firm owns one plant. If both firms lose their reputations for food safety, then the single-plant firm loses $50 million and the two-plant firm loses $100 million. Thus, multiplant firms would be willing to invest more in auditor services and food safety technology than single-plant firms.

Firms that own more than one plant may have lower costs of implementing food safety technologies. Firms experience a learning curve when adopting

[6] This is a simple hypothetical example, not intended to be factually correct. Actual costs to these two types of plants would be very different than those expressed here. However, the example is valid since there still would be a large difference in costs.

more advanced technology, enabling multiplant firms to install and implement new technologies in other plants at a lower cost after they have already used it in one plant. This may be why Dunne (1994) found that multiplant firms were more likely to invest in manufacturing technologies than single-plant firms.

Summary

Due to their size, large plants find it necessary to invest more in high-speed food safety technologies to provide the food safety they need to meet their customers' demands. They also may suffer a greater financial loss than small plants if they have a food safety failure, have lower per-unit cost of food safety fixed-cost investments, and may have lower financing costs. Thus, it is no surprise that Dunne (1994) found that larger plants were more likely to adopt new manufacturing technologies and Ollinger, Moore, and Chandran (2004) and Muth (2002) found that large meat and poultry plants make greater use of food safety technology than small plants do. For similar reasons, firms that own more than one plant may make greater use of food safety technology and auditor services than single-plant firms.

Our discussion of audit arrangements and food safety performance suggests that single-audit plants (customer- or plant-hired auditors) may emphasize food safety less than double-audit type plants (customer- and plant-hired auditors). Similarly, a single-audit plant may emphasize food safety more than a no-audit plant of a similar size. Economic theory suggests that if a plant values food safety higher, then it will invest more in food safety, suggesting an association between auditor use and food safety technology use.[7] Thus, we expect food safety technology levels to be higher for double-audit plants than for single-audit plants and for audit plants than for no-audit plants.

[7]Ollinger and Moore (2009) showed that food safety technology negatively affects *Salmonella* levels in meat and poultry products, suggesting that processors who place a higher value on food safety invest more in food safety technology.

Survey Techniques and the Data

Plant data on self-reported food safety technologies and practices were obtained from a national survey of Federal and State-inspected meat slaughter, poultry slaughter, and processing-only plants. The survey was sponsored by FSIS and conducted by RTI International in 2004 for meat and poultry slaughter plants and in 2005 for processing-only plants. The analysis described in this report focuses on federally inspected plants.[8]

A detailed description of the multimodal survey approach used for administering the surveys is given in Cates et al. (2005, 2006). The survey instrument and study design were approved under the U.S. Office of Management and Budget's information collection clearance process. A brief overview of the sampling methods, questionnaire development, survey administration, and analysis procedures is given in appendix A.

The analyses compare large and small plants. We defined large plants as those plants falling in the top quintile of volume of production (80-99 percentile) and the small plants as those falling in the bottom quintile (0-19 percentile). The distributions of plants by quintile and total numbers of plants for each of the six analysis categories are provided in table 1.

[8]Virtually all State-inspected plants are in the very small size category, with nine or fewer employees.

Variable Measurement

There are four types of variables used in the analysis: an indicator for each of the four types of audits, whether the plant was owned by a single- or multi-plant firm, plant size, and food safety technology. Our measures of plant audit type were taken directly from the survey and include one no-audit, two single-audit, and one double-audit types. Single-audit plants have either audits sponsored by customers or audits sponsored by the plant or the parent (owner) of the plant. Double-audit plants have audits by both customers and the plant.

Table 1
Plants in each size quintile by type

Plant type	Size percentiles (ranked by pounds of output) 0–19	20–39	40–59	60–79	80–99	Total number
	Number of plants					
Slaughter[1]						
Cattle slaughter	52	53	53	53	53	264
Hog slaughter	51	52	51	52	51	257
Poultry slaughter	40	41	41	41	41	204
Processing only						
RTE products	32	33	32	33	32	162
NRTE products	42	42	44	42	41	211
Ground beef	15	16	17	13	18	79

[1]Slaughter industries includes plants that only slaughter animals (i.e., slaughter-only plants) and plants that both slaughter animals and process raw meat.
RTE=Ready To Eat.
NRTE=Not Ready To Eat.
Source: USDA, Economic Research Service and RTI calculations.

The measure of whether the plant was owned by a single- or multiplant firm was taken from a survey question asking whether a plant has a parent company that owns other plants. Plant size is based on pounds of production per year and was calculated by summing responses to the volume questions in the surveys.[9] There were 74 meat slaughter and 16 poultry slaughter plants that did not give production volumes. For these plants, we calculated estimated values based on 2004 slaughter volumes obtained from FSIS's Animal Disposition Reporting System. Since output is reported in animals slaughtered in this dataset, we converted animals slaughtered to their weight equivalent. We did this by multiplying the number of animals slaughtered times the average dressed weight of that animal. Output volumes for poultry species were defined as the number of birds slaughtered times the average live weight times the average dressing percentage. Average dressed (carcass) weights, live weights, and dressing percentages for meat species in 2004 were obtained from USDA/ERS *Red Meat Yearbook*; average live weights for poultry species in 2004 were obtained from USDA/National Agricultural Statistical Service *Poultry Yearbook*; and, average dressing percentages for poultry were obtained from USDA/Agricultural Marketing Service Market News for the week ending November 1, 2008. Dressing percentages for 2008 were used because estimates were not available for 2004.[10] Note that for two meat slaughter plants, slaughter volumes for 2004 were not available, so we used their 2003 volumes. Furthermore, for five poultry slaughter plants, slaughter volumes for 2004 were not available, so we used 2003 volumes (four plants) or 2002 volumes (one plant).

[9]For meat slaughter, the volume questions were 1.5 and 2.12. For poultry slaughter, the volume questions were 1.5 and 2.11; see: http://www.fsis.usda.gov/PDF/SRM_Survey_Slaughter_&_Processing_Plants.pdf/. For processing-only plants, the volume questions were 1.12 through 1.15; see: http://www.fsis.usda.gov/PDF/SRM_Survey_Meat_&_Poultry_Processing_Only_Plants.pdf /.

[10]The meat species and carcass weight are: steers–806 pounds, heifers–740 pounds, cows–614 pounds, bulls–893 pounds, veal calves–201 pounds, barrows and gilts–196 pounds, sows–313 pounds, boars–220 pounds, sheep–66 pounds, lambs–69 pounds, goats–25 pounds, and other meat species–684 pounds (assumed bison). The poultry species, carcass weight, and dressing percentage for poultry are: Young chickens–5.27 pounds and 74.5 percent, mature chickens–5.66 pounds and 74.5 percent, light fowl–3.35 pounds and 51.5 percent, heavy fowl–8.03 pounds and 66.5 percent, young turkeys–27.12 pounds and 80.0 percent, old turkeys–26.84 pounds and 76.0 percent, ducks–6.71 pounds and 72.0 percent, and other poultry–1.0 pounds (assumed squab).

Construction of a Food Safety Technology Index

We constructed a food safety technology index based on a methodology discussed in an earlier ERS report (Ollinger, Moore, and Chandran, 2004). This technology index is grounded on the idea that food safety process control is a system in which plants marshal several different types of equipment and practices to maintain process control— produce meat or poultry that is free of harmful contaminants.

It is more precise to compare similar technologies and production practices across plants (e.g., equipment of one plant to equipment of another) rather than an overall system of food safety that includes a mixture of technologies and practices. Thus, we created five food safety technology indexes that correspond with questions in the survey. These five technologies are:

- Dehiding/slaughter (cattle and hog slaughter only)—method of removing the hide from (dehiding) carcasses, sanitizing practices and frequencies in the slaughter areas, and whether a plant requires its animal suppliers to meet pathogen-control standards.
- Sanitation—sanitizing practices and frequencies in the further processing areas and removal of biomatter.[11]
- Operations—use of written policies and procedures for recalls, tracking products backward and forward, whether a plant requires its meat suppliers to meet pathogen-control standards, employee food safety training, use of dedicated manager and staff for food safety activities, etc.

[11]Further processing areas include meat and poultry preparation areas. It includes cutting, deboning, trimming, grinding, cooking, and other processing areas. This step precedes packaging products for the consumer.

- Equipment—use of food safety equipment and other technologies in the slaughter area (e.g., steam vacuum units or organic acid rinses) and processing area (e.g., high pressure processing or application of antimicrobials).

- Testing—pathogen testing practices, organisms tested, and testing frequencies.

Three principles were followed in creating the food safety technology index. First, the rating system should be monotonic because more intensive operations should yield greater food safety protection than less intensive ones. For example, plants with more intensive cleaning or that use a specific piece of food safety equipment should have higher scores than plants with less intensive cleaning or without the same piece of equipment. Second, comparisons should be made for technology types (see earlier discussion). Third, since food safety quality control requires a systematic approach, a variety of technology components within each technology type should be considered. For example, steam vacuum units, carcass pasteurizers, and various sanitizing sprays are important technologies, included in the overall and equipment indexes, and considered by meat experts as components of an effective process control system.

Construction of the index followed several general procedures that are described in appendix B and lead to an index that ranges from 0 to 1. That discussion can be summarized as follows. If plants do not use a type of food safety equipment or procedure, they were assigned 0 points for that technology, and, if the procedure or equipment is used, then they were assigned 1 point. If plants used an intermediate level of a procedure or task, then point values falling between 0 and 1 were assigned. For example, if the options for cleaning were once per week, once per day, once per shift, or once per hour and the plant chose once per shift, then it would be assigned a number between 0 and 1e. After assigning values, all assigned values were added together and the resulting sum was divided by the total number of questions used to create that particular index (e.g., sanitation). Appendix table B1 gives the survey questions supporting each technology index for each technology type for the cattle, hog, and poultry slaughter and processing industries and all processing-only plants.

Data Discussion

Tables 2, 3, and 4 present pounds of output by plant size and type of industry and type of outside auditor.[12] Table 2 shows that the largest plants are very much larger than the smallest plants when measured in terms of pounds of output. Cattle and hog slaughter plants in the top quintile produced more than 10,000 times more pounds of output than competitors in the bottom quintile. Plants in the top quintile in other industries were between 100 and 1,000 times larger in terms of pounds of output than their competitors in the bottom quintile. Notice also that slaughter plants in the top quintile were 15-45 times larger in terms of output than the largest processing-only plants, but cattle and hog plants in bottom quintiles were about the same size as the processing-only plants. Finally, poultry plants in all quintiles are larger than their counterparts in other industries.

Tables 3 and 4 show auditing practices by quintile. More than 80 percent of plants in the top quintile of each industry were subject to audits of any type, while from 55 to 90 percent of plants in the bottom quintile of each industry had no audits. The majority of plants in the top quintile of all but the not-ready-to-eat (NRTE) industry were double-audit plants (i.e., used both customer-hired and plant-hired auditors). Most plants in the bottom quintile of each industry had no audits, and a majority of plants in the bottom three quintiles in all industries except poultry slaughter were no-audit plants.

Appendix table B1 shows that cattle and hog slaughter plants in the top quintiles were mainly single-species plants (i.e., either cattle-only or hog-only);

[12]Appendix tables B2-B4 show the number of animals slaughtered by industry and plant size and output shares by industry and size.

Table 2
Slaughter and processing industries: Output per plant per industry quintile[1]

	Plant size quintile (ranked by pounds of output)				
Plant type	0–19	20–39	40–59	60–79	80–99
	Mean pounds per plant				
Slaughter[1]					
Cattle slaughter	28, 042	157,808	508,319	3,328,599	317,592,240
Hog slaughter	23,999	137,691	445,834	2,717, 570	293,875,382
Poultry slaughter	4,405,970	66,701,669	151,698,487	228,093,237	450,675,247
Processing only					
RTE products	13,125	132,273	651,563	7,966,818	22,262,813
NRTE products	22,024	126,310	550,114	3,680,952	13,292,927
Ground beef	30,667	196,875	752,059	5,038,462	11,358,056

Notes: Mean pounds for slaughter were calculated by multiplying number of head slaughtered by average carcass weight pounds (lbs) per head as reported in USDA's Red Meat Yearbook and Poultry Yearbook for 2004. The meat species and carcass weight are: steers–806 lbs, heifers–740 lbs, cows–614 lbs, bulls–893 lbs, veal–201 lbs, barrows and gilts–196 lbs, sows–313 lbs, boars–220 lbs, sheep–66 lbs, lambs–69 lbs, goats–25 lbs, and other meat species–684 lbs (assumed bison). The poultry species, carcass weight, and dressing percentage for poultry are: young chickens–5.27 lbs and 74.5 percent, mature chickens–5.66 lbs and 74.5 percent, light fowl–3.35 lbs and 51.5 percent, heavy fowl–8.03 lbs and 66.5 percent, young turkeys–27.12 lbs and 80.0 percent, old turkeys–26.84 lbs and 76.0 percent, ducks–6.71 lbs and 72.0 percent, and other poultry–1.0 pound (assumed squab).
[1] Slaughter industries includes plants that only slaughter plants (i.e., slaughter-only plants) and plants that both slaughter animals and process raw meat.
RTE=Ready To Eat.
NRTE=Not Ready To Eat.
Source: USDA, Economic Research Service and RTI calculations.

Table 3

Slaughter industries: Types of outside auditors per plant size quintile[1]

Plant type	Size percentiles (ranked by pounds of output)				
	0–19	20–39	40–59	60–79	80–99
	Percent				
Cattle slaughter					
Single audit I	12.0	11.5	16.0	11.8	15.7
Single audit II	2.0	5.8	0.0	5.9	9.8
Double audit	0.0	1.9	2.0	7.8	62.8
No audit	86.0	80.8	82.0	74.5	11.8
Hog slaughter					
Single audit I	8.2	8.0	16.7	8.0	17.7
Single audit II	2.0	6.0	0.0	8.0	13.7
Double audit	0.0	2.0	0.0	2.0	47.1
No audit	89.8	84.0	83.3	82.0	21.5
Poultry slaughter					
Single audit I	26.3	22.0	15.4	17.5	22.0
Single audit II	7.9	24.4	20.5	7.5	17.1
Double audit	10.5	46.3	56.4	75.0	61.0
No audit	55.3	7.3	7.7	0.0	0.0

[1] Slaughter industries includes plants that only slaughter plants (i.e., slaughter-only plants) and plants that both slaughter animals and process raw meat.
Single audit I= Customer or customer-hired auditor.
Single audit II=Plant- or parent company-hired auditor.
Double audit=Customer or customer-hired auditor AND plant- or parent company-hired auditor.
Source: USDA, Economic Research Service and RTI calculations.

Table 4

Processing-only industries: Types of outside auditors per plant size quintile

Plant type	Size percentiles (ranked by pounds of output)				
	0–19	20–39	40–59	60–79	80–99
	Percent				
RTE products					
Single audit I	21.9	18.8	12.5	28.1	21.9
Single audit II	9.4	15.6	15.6	9.4	18.8
Double audit	6.3	6.3	12.5	43.8	53.1
No audit	62.5	59.4	59.4	18.8	6.3
NRTE products					
Single audit I	2.5	10.0	9.3	17.1	24.4
Single audit II	17.5	10.0	16.3	9.8	29.3
Double audit	5.0	0.0	4.7	17.1	26.8
No audit	75.0	80.0	69.8	56.1	19.5
Ground beef					
Single audit I	0.0	12.5	5.9	33.3	33.3
Single audit II	26.7	6.2	29.4	25.0	16.7
Double audit	0.0	6.3	0.0	0.0	44.4
No audit	73.3	75.0	64.7	41.7	5.6

[1]RTE=Ready To Eat.
NRTE=Not Ready To Eat.
Single audit I= Customer or customer-hired auditor.
Single audit II=Plant- or parent company-hired auditor.
Double audit=Customer or customer-hired auditor AND plant- or parent company-hired auditor.
Source: USDA, Economic Research Service and RTI calculations.

plants in the other quintiles slaughtered a wider mix of animals. Inputs for poultry slaughter were about the same for all quintiles.

Appendix tables B2 and B3 show output shares for the slaughter and processing-only industries. Primal cuts accounted for more than 80 percent of the output of cattle and hog slaughter plants in the top quintile. In contrast, three-fourths of the output of plants in the bottom quintile consisted of raw ground meat and processed products. Plants in the top and bottom quintiles of the other industries had similar output mixes. Poultry plants in all quintiles produced mainly raw, not ground products; half the output of plants of all quintiles in the ready-to-eat (RTE) industry was fully cooked, not shelf stable products; plants of all quintiles in the NRTE industry produced a mix of output; plants of all quintiles in the ground beef industry produced mainly raw ground meat.

Results

We examine differences in statistical means of the technology index across five size categories of plants, two firm types (whether the plant is a part of a single-plant or multiplant firm), four audit types, and five plant sizes and two audit types. We do pair-wise means tests for comparisons of two groups (e.g., single-plant versus multiplant firms). However, a different statistical test is required when there are more than two groups (e.g., comparisons of technology use across the five groups (quintiles) in table 5). It can be shown that a positive (significant) outcome is more likely if there are more comparisons. A Tukey-Kramer multiple comparison test is used in this study to adjust for the tendency to have false positives in series of pair-wise statistical tests. This multiple comparison test requires a stronger level of evidence for an individual comparison to be deemed "significant" than would a series of pair-wise means tests. Although there are other multiple comparison tests, the Tukey-Kramer method is most appropriate for our case because the data are unbalanced (SAS manual, p. 2,514, 2009).[13]

[13]See http://support.sas.com/documentation/cdl/en/statug/63033/html/default/viewer.htm#statug_glm_a0000000862.htm/ for more discussion.

Food Safety Technology Indexes and Plant Characteristics

Plant size

Table 5 shows that the food safety technology indexes increase with size and that there are sharp differences between plants in the top and bottom percentiles in the cattle and hog slaughter industries. In both industries, the technology index values were about one-third larger for plants in the top quintile relative to those in the bottom quintile. Based on the Tukey multiple comparison test, the index values for plants in the top cattle slaughter quintile were significantly larger than the index values for plants in the other four quintiles for all but the sanitation index ($p<0.01$). For sanitation, the index value for plants in the top quintile was significantly larger ($p<0.05$) compared to only plants in the bottom two quintiles. For hog slaughter, index values for plants in the top quintile were significantly larger for all but sanitation and dehiding. None of the dehiding index comparisons were significantly different.[14] For sanitation, the technology index for plants in the top quintile was significantly larger ($p<0.05$) when compared to only plants in the bottom two quintiles.

[14]Hog slaughter operations do not typically dehide hogs. Most dehiding operations in the hog industry are by multi-species plants that butcher both hogs and cattle.

Results for poultry slaughter differ from those for cattle and hogs. Plants in the top quintile have an average technology index value that is similar to plants in all but the bottom quintile. Based on the Tukey multiple comparison test, the technology index values for plants in the top four poultry slaughter quintiles were significantly larger than the bottom quintile for all but the sanitation and testing index ($p<0.01$). The testing index values for plants in the top three quintiles are significantly larger than the bottom quintile ($p<0.01$); none of the sanitation indexes were significantly different.

Table 6 shows that the technology indexes increase with size in the processing-only industries but the change is not nearly as sharp as in the slaughter industries. The overall, equipment, and testing indexes increase with size, but the sanitation index is flat or declining and the operations index rises modestly. For RTE plants, the top two quintiles are significantly larger than the bottom quintiles for the overall technology index ($p<0.10$) and for the equipment index ($p<0.01$). For the operations index, the top three quintiles are significantly larger than the bottom quintile ($p<0.10$). For the testing

Table 5
Slaughter industries: Technology indexes per plant size quintile[1]

Index type	Size percentiles (ranked by pounds of output) 0–19	20–39	40–59	60–79	80–99	All plants
	Mean index value[2]					
Cattle slaughter						
Overall index	0.32	0.32	0.35	0.37	0.54***	0.38
Dehiding	0.43	0.42	0.44	0.46	0.61***	0.47
Sanitation	0.56[bb]	0.55[bb]	0.65	0.65	0.71[aa]	0.62
Operations	0.46	0.44	0.46	0.45	0.57***	0.48
Equipment	0.11	0.13	0.15	0.18	0.51***	0.22
Testing	0.05	0.05	0.05	0.08	0.30***	0.11
Number of plants	50	52	50	51	51	254
Hog slaughter						
Overall index	0.31	0.32	0.36	0.34	0.46***	0.36
Dehiding	0.43	0.44	0.45	0.45	0.50	0.46
Sanitation	0.55 [bb]	0.55[bb]	0.65	0.62	0.71[aa]	0.62
Operations	0.44	0.46	0.46	0.42	0.57***	0.47
Equipment	0.10	0.12	0.15	0.15	0.36***	0.18
Testing	0.05	0.05	0.06	0.07	0.17***	0.08
Number of plants	49	50	48	50	51	248
Poultry slaughter						
Overall index	0.29 [bb]	0.41 [aa]	0.43 [aa]	0.45 [aa]	0.45[aa]	0.40
Sanitation	0.42	0.43	0.40	0.45	0.43	0.43
Operations	0.43 [bb]	0.59 [aa]	0.63 [aa]	0.61 [aa]	0.62 [aa]	0.58
Equipment	0.19 [bb]	0.43 [aa]	0.48 [aa]	0.50 [aa]	0.53 [aa]	0.43
Testing	0.11[bb]	0.18	0.21 [aa]	0.22 [aa]	0.23 [aa]	0.19
Number of plants	38	41	39	40	41	199

[1]Slaughter industries includes plants that only slaughter plants (i.e., slaughter-only plants) and plants that both slaughter animals and process raw meat.
[2] Index value varies from 0 to 1. *** significant relative to other 4 groups at the 1-percent level; [aa]significant at the 5-percent level relative to groups marked by [bb].
Source: USDA, Economic Research Service and RTI calculations.

index, the top quintile is significantly larger compared to the 20–39 percent and 40–59 percent quintiles ($p<.05$). Finally, none of the size quintiles for the sanitation index are significantly different.

The pattern for NRTE products is similar to that for RTE products. The index value for plants in the top quintile is significantly different and larger than plants in the bottom three quintiles for the overall technology index ($p<0.10$), values for plants in the top two quintiles are statistically significant and larger than values for plants in the bottom three quintiles for the equipment index ($p<0.01$), and the value for plants in the top quintile is statistically significant and larger compared to all other size categories for the testing index ($p<0.01$). Results for operations and sanitation are, in general, not significantly different.

For ground beef only, Tukey multiple comparison tests show that the index value of plants in the top quintile is significantly larger than values for plants in the four smaller size quintiles for the overall index ($p<0.01$), equipment

Table 6
Processing-only industries: Technology indexes per plant size quintile

Index type	Size percentiles (ranked by pounds of output) 0–19	20–39	40–59	60–79	80–99	All plants
	Mean index value[2]					
RTE products						
Overall index	0.32 [b]	0.34 [b]	0.38[b]	0.39 [a]	0.43 [a]	0.37
Sanitation	0.61	0.63	0.66	0.52	0.60	0.60
Operations	0.46	0.52	0.54	0.57	0.59	0.54
Equipment	0.14[bbb]	0.12 [bbb]	0.23 [bbb]	0.34 [aaa]	0.40 [aaa]	0.25
Testing	0.08	0.07 [bb]	0.08 [bb]	0.13	0.12[aa]	0.10
Number of plants	32	33	32	33	32	162
NRTE products						
Overall index	0.33 [b]	0.31 [b]	0.34 [b]	0.35	0.40 [a]	0.35
Sanitation	0.68	0.66	0.69	0.61	0.59	0.65
Operations	0.49	0.48	0.50	0.51	0.57	0.51
Equipment	0.10 [bbb]	0.06 [bbb]	0.10 [bbb]	0.21 [aaa]	0.29 [aaa]	0.15
Testing	0.04	0.04	0.05	0.09	0.15 ***	0.07
Number of plants	42	42	44	42	41	211
Ground beef						
Overall index	0.33	0.31	0.36	0.34	0.47***	0.37
Sanitation	0.64	0.58	0.71	0.57	0.66	0.64
Operations	0.56	0.50	0.56	0.53	0.61	0.55
Equipment	0.06	0.12	0.10	0.19	0.40***	0.18
Testing	0.04	0.06	0.07	0.08	0.21***	0.10
Number of plants	15	16	17	13	18	79

[1]Index value varies from 0 to 1. *** significant relative to other 4 groups at the 1-percent level; [aaa]significant at the 1-percent level relative to groups marked by [bbb]; [aa]significant at the 5- percent level relative to groups marked by [bb]; [a] significant at the 10- percent level relative to groups marked by [b].
RTE=Ready To Eat.
NRTE=Not Ready To Eat.
Source: USDA, Economic Research Service and RTI International calculations.

index ($p<0.01$), and testing index ($p<0.01$). Results for operations and sanitation are, in general, not significantly different.

Plant Ownership (Firm) Type

Tables 7 and 8 compare the technology index values for plants owned by single-plant firms to those owned by multiplant firms. Table 7 shows that the technology index values for slaughter plants owned by multiplant firms are significantly higher than for single-plant firms in 13 of 17 cases. Only dehiding in the hog industry and sanitation in all industries were not significantly different. Table 8 provides results for processing-only plants. The overall technology index value and the values for operations, equipment, and testing were significantly larger for multiplant firms than for single-plant firms in all three industries. Plants owned by single-plant firms had larger or equal index values for sanitation.

Table 7
Slaughter industries: Technology indexes by firm type[1]

	Firm type	
Index type	Single plant	Multiplant
	Mean index value[2]	
Cattle slaughter		
Overall index	0.36	0.52***
Dehiding	0.45	0.60***
Sanitation	0.62	0.65
Operations	0.46	0.58***
Equipment	0.17	0.49***
Testing	0.08	0.29***
Number of plants	221	40
Hog slaughter		
Overall index	0.34	0.46***
Dehiding	0.45	0.50
Sanitation	0.61	0.68
Operations	0.46	0.56***
Equipment	0.14	0.38***
Testing	0.06	0.16***
Number of plants	217	36
Poultry slaughter		
Overall index	0.30	0.44***
Sanitation	0.42	0.42
Operations	0.46	0.62***
Equipment	0.22	0.50***
Testing	0.10	0.21***
Number of plants	50	151

[1]Slaughter industries includes plants that only slaughter plants (i.e., slaughter-only plants) and plants that both slaughter animals and process raw meat.
[2] Index value varies from 0 to 1; *** Differences are statistically significant at the 1-percent level.
Source: USDA, Economic Research Service and RTI calculations.

Table 8
Processing-only, RTE processing plants: Technology indexes by firm type

Index type	Firm type	
	Single plant	Multiplant
	Mean index value[2]	
RTE products		
Overall index	0.35	0.41***
Sanitation	0.63***	0.56
Operations	0.50	0.58***
Equipment	0.17	0.37***
Testing	0.08	0.13***
Number of plants	97	62
NRTE products		
Overall index	0.32	0.42***
Sanitation	0.65	0.65
Operations	0.49	0.58***
Equipment	0.11	0.31***
Testing	0.05	0.16***
Number of plants	160	48
Ground beef		
Overall technology index	0.35	0.44***
Sanitation	0.64	0.62
Operations	0.54	0.61**
Equipment	0.14	0.34***
Testing	0.08	0.17***
Number of plants	63	16

RTE=Ready To Eat.
NRTE=Not Ready To Eat.
[1] Index value varies from 0 to 1; **, *** Differences are statistically significant at the 5-percent and 1-percent levels.
Source: USDA, Economic Research Service and RTI calculations.

Food Safety Technology by Audit Type

Single-audit plants (customer- or plant-hired auditors) may emphasize food safety less than double-audit type plants because only one side of an exchange (customer or plant) wants an audit while both parties of an exchange (customer and plant) want an audit in double-audit plants. A similar rationale can be applied for single-audit plants relative to no-audit plants. Thus, we expect the technology index to be greatest for double-audit plants, least for no-audit plants, and intermediate between these two for single-audit plants (either customer- or plant-hired).

Tables 9 and 10 show the overall and individual technology index values for plants using four types of auditing arrangements—no-audit, single-audit/customer-hired, single-audit/plant-hired, and double-audit. The technology value of double-audit slaughter plants is generally higher than the single-audit plants and is always higher than no audit (see table 9). Based on the Tukey multiple comparison tests for cattle and hog slaughter, equipment and

testing indexes are significantly larger for the double-audit type compared to the single-audit types (p<0.10). For poultry slaughter, only the operations comparison of the double-audit and the customer-hired audit is significantly different.

Table 10 shows that audited processing plants have higher technology index values than unaudited processing plants in all categories except sanitation. For RTE products, Tukey multiple comparison tests indicate that the overall index and all other indexes except the sanitation index are significantly larger for the double-audit arrangements than for either type of single-audit plants (<0.10). For NRTE products, Tukey multiple comparison tests indicate that the equipment and testing indexes are significantly larger for plants with double-audit arrangements than for single-audit plants (p<.05) but the

Table 9
Slaughter industries: Technology indexes by audit type[1]

	Audit type			
Index type	Single audit I	Single audit II	Double audit	No audit
	----------Mean index value[2]----------			
Cattle slaughter				
Overall index	0.41	0.46	0.55*	0.33
Dehiding	0.51	0.60	0.61	0.43
Sanitation	0.70	0.64	0.70	0.58
Operations	0.50	0.57	0.60	0.44
Equipment	0.26	0.34	0.52*	0.13
Testing	0.11	0.16	0.32*	0.06
Number of plants	34	12	38	170
Hog slaughter				
Overall index	0.38	0.42	0.49	0.33
Dehiding	0.47	0.52	0.51	0.44
Sanitation	0.66	0.69	0.68	0.59
Operations	0.50	0.53	0.61	0.44
Equipment	0.19	0.28	0.45*	0.13
Testing	0.08	0.11	0.21*	0.06
Number of plants	29	15	26	178
Poultry slaughter				
Overall index	0.40	0.42	0.44	0.27
Sanitation	0.44	0.39	0.44	0.39
Operations	0.55	0.60	0.62**	0.43
Equipment	0.42	0.47	0.48	0.18
Testing	0.20	0.21	0.21	0.07
Number of plants	41	31	100	27

[1]Slaughter industries includes plants that only slaughter plants (i.e., slaughter-only plants) and plants that both slaughter animals and process raw meat.
[2] Index value varies from 0 to 1; * , ** Differences are statistically significant at the 10-percent and 5-percent levels.
Single audit I=Customer or customer-hired auditor. Single audit II=Plant- or parent company-hired auditor.
Double audit=Customer or customer-hired auditor AND plant- or parent company-hired auditor.
Source: USDA, Economic Research Service and RTI calculations.

overall, sanitation, and operations indexes are not significantly different across audit types. For ground beef, double-audit arrangements are significantly larger than single-audit relationships only for testing and equipment. The other comparisons are not significantly different.

Food Safety Technology Differences by Audit Status and Plant Size

These results generally show that double-audit plants have higher technology indexes than single-audit plants, and both double- and single-audit plants have higher technology indexes than no audit plants. These results are important but incomplete. If all double-audit plants are also very large and smaller plants are all single- or no-audit plants, then it could be that size explains the higher technology index value for double-audit plants. In tables 11 and 12, we control for size and examine technology index values by audit status.

Table 10
Processing-only industries: Technology indexes by audit type

Index type	Audit type			
	Single audit I	Single audit II	Double audit	No audit
	Mean index value[2]			
RTE products				
Overall index	0.39	0.36	0.43*	0.34
Sanitation	0.60	0.59	0.57	0.63
Operations	0.56	0.49	0.59*	0.51
Equipment	0.28	0.26	0.41*	0.13
Testing	0.12	0.09	0.13*	0.08
Number of plants	33	22	39	66
NRTE products				
Overall index	0.39	0.39	0.43	0.31
Sanitation	0.64	0.68	0.61	0.64
Operations	0.56	0.56	0.56	0.48
Equipment	0.23	0.21	0.36**	0.08
Testing	0.12	0.10	0.20**	0.04
Number of plants	26	34	22	123
Ground beef				
Overall index	0.42	0.38	0.44	0.32
Sanitation	0.66	0.66	0.57	0.63
Operations	0.60	0.60	0.57	0.52
Equipment	0.28	0.15	0.43*	0.11
Testing	0.13	0.13	0.21*	0.05
Number of plants	13	16	9	40

[1]Index value varies from 0 to 1; *, ** Differences are statistically significant at the 10-percent and 5-percent levels.
Single audit I=Customer or customer-hired auditor.
Single audit II=Plant- or parent company-hired auditor.
Double audit=Customer or customer-hired auditor AND plant- or parent company-hired auditor.
RTE=Ready To Eat.
NRTE=Not Ready To Eat.
Source: USDA, Economic Research Service and RTI calculations.

Tables 11 and 12 compare the technology index values for all meat and poultry plants by audit status for only those plants in the top and bottom quintiles. By audit status, we mean the extent to which a plant is subject to any audit-type (either single-, no-, or double-audit). Table 11 shows that 14 of the 15 technology indexes for the slaughter industries are significantly different for the all-plant comparison. The table also shows that the testing and equipment indexes, but not other indexes, are significantly different in the top quintile for both hog and cattle slaughter. There were no unaudited poultry slaughter plants in the top quintile, suggesting that audit service had become universally accepted as a food safety tool for that industry.

Results of the comparison of audited and unaudited plants are weaker for the bottom quintile. There were no significantly different differences in the technology index between audited and unaudited hog slaughter plants in the

Table 11
Slaughter industries: Technology indexes by audit status and plant size quintile[1]

Index type	Size percentiles (ranked by pounds of output)					
	0–19		80-99		All plants	
	Audited	Unaudited	Audited	Unaudited	Audited	Unaudited
	Mean index value[2]					
Cattle slaughter						
Overall index	0.39*	0.31	0.55**	0.46	0.48***	0.33
Dehiding	0.49	0.43	0.62	0.55	0.57***	0.43
Sanitation	0.70	0.52	0.69	0.78	0.69***	0.58
Operations	0.53	0.45	0.59	0.52	0.56***	0.44
Equipment	0.18**	0.10	0.53**	0.32	0.39***	0.13
Testing	0.05	0.05	0.33***	0.15	0.21***	0.06
Number of plants	7	43	45	6	84	170
Hog slaughter						
Overall index	0.37	0.30	0.47	0.44	0.43***	0.33
Dehiding	0.48	0.42	0.49	0.55	0.50**	0.44
Sanitation	0.66	0.53	0.70	0.77	0.67**	0.59
Operations	0.52	0.42	0.59***	0.50	0.55***	0.44
Equipment	0.14	0.09	0.39**	0.26	0.30***	0.13
Testing	0.05	0.04	0.18***	0.10	0.13***	0.06
Number of plants	5	44	40	11	70	178
Poultry slaughter						
Overall index	0.36***	0.23	0.45	—	0.43***	0.27
Sanitation	0.47	0.39	0.43	—	0.43	0.39
Operations	0.51**	0.38	0.62	—	0.60***	0.43
Equipment	0.26***	0.12	0.53	—	0.47***	0.18
Testing	0.18**	0.04	0.23	—	0.21***	0.07
Number of plants	17	21	41	0	172	27

[1]Slaughter industries includes plants that only slaughter plants (i.e., slaughter-only plants) and plants that both slaughter animals and process raw meat.
[2] Index value varies from 0 to 1; *, **, *** Differences are statistically significant at the 10-percent, 5-percent, and 1-percent levels.
RTE=Ready To Eat.
NRTE=Not Ready To Eat.
Source: USDA, Economic Research Service and RTI calculations.

bottom quintile and only the overall and equipment indexes were significantly higher for cattle slaughter plants in the bottom quintile. By contrast, all technology indexes, except sanitation, were significantly larger for audited relative to unaudited poultry slaughter plants. These weaker results for the bottom quintile may be due to the distribution of audited and unaudited plants. Only 20 percent of the slaughter plants in the bottom quintile had audits, and most of those were poultry slaughter plants. By contrast, about 90 percent of plants in the top quintile had audits.

Table 12 shows that audited processing plants have significantly larger technology index values than unaudited processing plants in all technologies except sanitation in the all-plant comparison. Differences are not significantly different between audited and unaudited plants in the top quintile for RTE and ground beef products. This may be because only one or two plants were not audited in those quintiles. For the second-highest quintile (60 percent-79 percent–not shown), the technology index values for the overall, operations, and equipment technology indexes were significantly larger for audited RTE

Table 12
Processing only: Technology indexes by audit status and plant size quintile

Index type	Size percentiles (ranked by pounds of output)					
	0–19		80-99		All plants	
	Audited	Unaudited	Audited	Unaudited	Audited	Unaudited
	Mean index value[1]					
RTE products						
Overall index	0.35	0.31	0.43	0.46	0.40***	0.34
Sanitation	0.64	0.59	0.59	0.71	0.59	0.63
Operations	0.44	0.47	0.59	0.55	0.56***	0.51
Equipment	0.23**	0.09	0.39	0.44	0.33***	0.13
Testing	0.09	0.07	0.12	0.12	0.12***	0.08
Number of plants	12	20	30	2	94	66
NRTE products						
Overall index	0.42***	0.30	0.42***	0.31	0.40***	0.31
Sanitation	0.80*	0.65	0.61	0.51	0.65	0.64
Operations	0.58**	0.47	0.58	0.53	0.56***	0.48
Equipment	0.22***	0.06	0.32**	0.15	0.25***	0.08
Testing	0.09**	0.02	0.17***	0.05	0.13***	0.04
Number of plants	10	30	33	8	82	123
Ground beef						
Overall index	0.39*	0.30	0.47	0.39	0.41***	0.32
Sanitation	0.77	0.60	0.66	0.57	0.64	0.63
Operations	0.62	0.54	0.61	0.58	0.59***	0.52
Equipment	0.11	0.04	0.41	0.33	0.26***	0.11
Testing	0.08**	0.03	0.21	0.07	0.15***	0.05
Number of plants	4	11	17	1	38	40

RTE=Ready To Eat.
NRTE=Not Ready To Eat.
[1] Index value varies from 0 to 1; **, *** Differences are statistically significant at the 5-percent and 1-percent levels.
Source: USDA, Economic Research Service and RTI calculations.

plants than for unaudited ones. For the second-highest quintile for ground beef, only the testing and equipment indexes were significantly larger.

Results for the NRTE plants are stronger. Audited plants in the all-plant comparison have significantly higher technology index values for the overall, operations, equipment, and testing indexes. Audited NRTE plants in the top quintile have significantly larger index values than unaudited plants in all technologies except sanitation and operations, and audited NRTE plants in the bottom quintile have significantly larger index values than unaudited plants in all technologies.

Similar to the slaughter industries, relatively few processing plants in the bottom quintile have audits. Only about 30 percent of the NRTE plants in the bottom quintile had audits. By contrast, nearly 90 percent of NRTE plants in the top quintile had audits.

Concluding Discussion

Providing an economic framework and then testing several implications of that framework with simple means tests, Tukey multiple comparison tests, and other univariate methods allowed us to examine the incentives of meat and poultry plant managers to use food safety auditors and food safety technologies.

We find that meat and poultry plants that are subject to audits have higher food safety technology indexes than plants not subject to audits. We also find (1) that double-audit plants (at least one auditor hired by customer and one hired by plant) had higher index values than both no- and single-audit plants for all technologies except sanitation and operations, (2) single-audit plants (at least one auditor hired by either customer or plant) generally had higher index values than no-audit plants for all technologies except sanitation and operations, and (3) large plants and plants owned by multiplant firms have higher food safety technology indexes than their small and single-plant competitors.

This work both updates and extends earlier work by Ollinger, Moore, and Chandran (2004) by showing that plant size is correlated with a food safety technology index at a different point in time (2004 versus 2001) and by showing that the technology indexes are correlated with food safety audits. It is interesting to observe that the sanitation index is higher only for audited versus unaudited plants in the cattle and hog slaughter industries and not other industries. We attribute this outcome to FSIS's regulatory focus. FSIS stresses cleaning and sanitation, but mandates very little fixed investment and testing. This regulatory focus on sanitation may reduce the marginal improvements achievable through even more sanitation but may not affect the gains from other food safety technologies and practices. Thus, managers may be making discretionary food safety investments in non-sanitation technologies—operations, equipment, testing, and dehiding—since those technologies (1) may provide greater marginal improvement in food safety process control and (2) may offer a wider range of practices and technologies that can be used.

It is very important to remember that, since univariate methods were used in the analysis, we did not control for other factors affecting the use of food safety technologies. Thus, the results provide some, but not complete confidence of an association between a technology index and a group of plants classified by their size, firm type, and audit arrangements.[15]

[15] Survey responses were self-reported by the plant, which increases the likelihood of receiving biased information, particularly since the survey was conducted for FSIS, a regulatory agency. However, we believe most of the data are accurate because (a) the questionnaire stated that the responses would be kept confidential, (b) the questionnaire said that only aggregated information would be provided to FSIS, and (c) most of the questions dealt with the use of technologies and not more sensitive information. It was not within the scope of the study to verify the responses through onsite visits or other methods.

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Appendix A: Survey Procedures

Sampling Methods. The sampling frame was a Food Safety and Inspection Service, USDA, database of Federal and State-inspected plants that contains plant-level information on production volume, annual revenue, number of employees, inspection activities, and contact information from various USDA sources. All commercial plants that currently slaughter meat species (cattle, swine, lamb, goat, and other meat species) or poultry species (chicken, turkey, and other poultry species) were included in the sampling frame for the slaughter surveys. All commercial plants that do not slaughter but conduct further processing of meat and poultry were included in the sampling frame for the processing-only survey. Custom-exempt plants were excluded.[16] The sample was stratified by inspection status (Federal versus State) and hazard analysis and critical control points (HACCP) size (very small, small, and large) as follows:

- large plants have 500 or more employees,
- small plants have 10 or more employees but fewer than 500, and
- very small plants have fewer than 10 employees or less than $2.5 million in annual sales.

The sample design specified a sample size that was expected to yield precision of +/–5 percent or better for estimates of all proportions. For federally inspected plants, a systematic sample of very small plants and a census of small and large plants were included.[17]

Questionnaire Development. The questionnaire was designed to collect information on the use and frequency of sanitation practices, use of specific food safety technologies and practices, use and types of microbiological testing, food safety training procedures, response to the bovine spongiform encephalopathy (BSE) interim final rules by beef packing plants, and plant characteristics (e.g., age, size, and number of shifts). Plants were asked to provide information on their activities during the past year. The slaughter surveys were administered in 2004, and the processing-only survey was administered in 2005. Before administering the survey, the questionnaires were reviewed by trade associations and pretested with a small number of plants.

Survey Administration. A variety of procedures aimed at maximizing the survey response rate were used, including many of the procedures recommended by Dillman (2000). Before the start of data collection, several industry trade organizations sent an e-mail message to their membership or posted information in their newsletter and on their website that described the survey and encouraged their participation. Sampled plants were contacted by telephone to identify the plant manager and then mailed a letter on FSIS letterhead that described the upcoming survey. Plant managers were contacted by telephone to screen for eligibility and to identify the target respondent for the survey (if not the plant manager). The self-administered questionnaire was delivered via Federal Express followed by a thank you/reminder postcard. Respondents completed the mail questionnaire and sent it back to RTI for keying. Those who did not respond were reminded

[16]Custom-exempt plants can only slaughter and process livestock for the exclusive use of the owner.

[17]Systematic sampling ensures that the selected sample represents the population by forcing the sample to include plants with varying characteristics, such as geographic location and type of species.

through a series of telephone calls, and the questionnaire was remailed to nonrespondents.

The numbers of respondents and response rates for each of the surveys are provided in appendix table A1.

From each of the survey datasets, we created analysis datasets to focus on categories of interest as follows:

- For **cattle slaughter** plants, the original dataset included 384 federally inspected plants that slaughtered hooved animals. Plants that slaughtered only veal calves (4 plants), only cows and bulls (12 plants), or only other meat species were excluded, resulting in a final dataset of 264 plants that slaughtered steers and heifers. Plants that also slaughtered hogs in addition to steers and heifers were retained in the dataset.
- For **hog slaughter** plants, the original dataset included 384 federally inspected plants that slaughtered hooved animals. Plants that slaughtered only sows and boars (19 plants) or only other meat species were excluded, resulting in a final dataset of 257 plants that slaughtered market hogs. Plants that also slaughtered cattle in addition to barrows and gilts were retained in the dataset.
- For **poultry slaughter** plants, the original dataset included 218 federally inspected plants that slaughtered young chickens or young turkeys. Of these, 14 plants that slaughtered only poultry species other than young chickens or young turkeys were deleted, resulting in a final dataset of 204 plants.
- For **processing-only plants that produce processed products**, the original dataset included 667 federally inspected plants. Of these, 294 were deleted (281 that produced only products for further processing or produced both RTE and NRTE products and also 13 plants with no

Appendix table A1

Survey response rates for federally inspected plants

	Meat slaughter and processing	Poultry slaughter and processing	Processing only
	----------*Number*----------		
Respondents	384	212	672
Nonrespondents	132	45	260
Unknown eligibility	24	11	56
Ineligibles[a]	50	21	98
Total sample	590	289	1,086
	----------*Percent*----------		
Weighted response rate[b]	70	80	68

[a] Ineligibles include plants that were classified as slaughter plants but were determined not to have a slaughter operation, to conduct custom slaughter only, or to be out of business.
[b] The weighted response rate was calculated using the survey weights adjusted for unknown eligibility.
Sources: Cates, S.C., C.L. Viator, S.A. Karns, and P.H. Siegel. 2005. *Survey of Meat and Poultry Slaughter and Processing Plants*, Research Triangle Park, NC: RTI.
Cates, S.C., S.A. Karns J.L. Taylor, C.L. Viator, and P.H. Siegel. 2006. *Survey of Meat and Poultry Processing-Only Plants*, Research Triangle Park, NC: RTI.

production volumes). The resulting dataset includes 162 RTE-only plants and 211 NRTE-only plants.

- For **processing-only plants that produce ground beef**, we included a plant in the dataset if at least 25 percent of its production volume was ground beef. From the original 166 plants with a nonzero ground beef production volume, the resulting dataset includes 79 plants.

Appendix B: Index Construction and Descriptive Statistics

Survey questions supporting each food safety technology index for each food safety technology category for cattle, hog, and poultry slaughter and processing plants and meat and poultry processing-only plants, as well as the technology or practice can be found at:

- Slaughter survey questions: http://www.fsis.usda.gov/PDF/SRM_Survey_Slaughter_&_Processing_Plants.pdf/.
- Processing-only plant questions: http://www.fsis.usda.gov/PDF/SRM_Survey_Meat_&_Poultry_Processing_Only_Plants.pdf /.

The indexes were constructed as follows. First, we grouped similar technologies and practices into one of the five types of food safety practices and technologies described above. Second, we valued all questions equally with a maximum value of 1 and a minimum value of 0. Third, we assigned the most intensive operation within each question a value of 1 and the least intensive a value of 0. For example, equipment usage questions and similar questions had just two possible responses: 1 or 0. Many sanitation and plant operations questions, however, had multiple choices. For these questions, we assigned a 1 to operations that generate the most food safety, a 0 to operations generating the least food safety, and an intermediate value between 0 and 1 for operations providing intermediate food safety performance. Intermediate values could have been chosen on a linear, logarithmic, or some other monotonic scale. We assumed a linear relationship. Thus, if five response choices were provided, then values would be in fourths (0.0, 0.25, 0.50, 0.75, and 1.0) and, if four response choices were given, then values would be thirds (0.0, 0.33, 0.67, 1.0).

Finally, we created a technology index for each technology category by summing the values of the responses for each of the questions within that category—plant equipment, testing procedures, plant operations, sanitation, and dehiding—and dividing by the number of questions, yielding an index value between 0 and 1. For the overall technology category, we divided the total of all technology questions by the total number of food safety technology questions. Examples of the index are given in Ollinger, Moore, and Chandran (2004)

Although we tried to create as precise an index as possible, it is important to recognize that the index is not exact. First, we chose a linear scale to weigh intermediate survey questions. Second, all pathogen-control activities within a category were assumed to be of equal importance. For example, sanitizing knives is of equal importance to washing hands and each of those is equal to the use of a steam vacuum unit. But, it may be that sanitizing knives is more important than washing hands and the steam vacuum units, in which case knife sanitation should have a heavier weight. Third, the five technology categories may not be of equal importance. For example, it may be that sanitation and cleaning is more important than equipment. To partially accommodate this concern, we emphasize the categorical (e.g., index of

pathogen-control equipment) rather than the overall pathogen-control plant rating in our discussion.

Fourth, several procedures employed in order to make a survey response usable may have influenced the final index values:

- A value of 0 for binary responses and the midpoint value for frequency responses (responses with more than a 0/1 choice, such as a scale) were assigned if the question had a missing response that was not attributed to a skipped question. This might have had the tendency to reduce the technology index value for some plants.
- For questions with multiple responses (e.g., circle all that apply), we used the response with the highest index value.

Appendix table B1

Survey questions supporting technology indexes for meat and poultry slaughter industries[1]

Type of plant	Technology	Question number
Cattle slaughter	Dehiding	1.2, 1.6, 1.7, 1.9, 1.9a, 1.9c-e, and 3.2;
	Sanitation	2.9, 2.10, 2.11, 2.13, 2.13c-g, and 5.6
	Operations	1.9f, 1.9j, 1.9k, 2.13a, 2.13h, 4.1, 4.2, 4.3, 5.8, 5.9, and 5.11
	Equipment	1.8a-k and 2.14a-g
	Testing	3.1, 3.3, 3.4a-j, 3.5, 3.6a-j, 3.7, 3.8a-k, 3.9, 3.10a-h, 3.11, 3.12a-e, 3.13a-e, and 3.14
Hog slaughter	Dehiding	1.2, 1.6, 1.7, 1.9, 1.9a, 1.9c-e, and 3.2;
	Sanitation	2.9, 2.10, 2.11, 2.13, 2.13c-g, and 5.6
	Operations	1.9f, 1.9j, 1.9k, 2.13a, 2.13h, 4.1, 4.2, 4.3, 5.8, 5.9, and 5.11
	Equipment	1.8a-k and 2.14a-g
	Testing	3.1, 3.3, 3.4a-j, 3.5, 3.6a-j, 3.7, 3.8a-k, 3.9, 3.10a-h, 3.11, 3.12a-e, 3.13a-e, and 3.14
Chicken slaughter	Sanitation	1.2, 1.3, 1.7c-e, 2.12, 2.13, 2.14, 2.9c-g, and 5.7
	Operations	1.7a, 1.7f, 1.7j, 1.7k, 2.9a, 2.9h, 4.1, 4.2, 4.3, 5.9, 5.1d, 5.12
	Equipment	1.6a-g and 2.10a-g
	Testing	3.1, 3.2, 3.3a-k, 3.4, 3.5a-k, 3.6, 3.7a-i, 3.8, 3.9a-i, 3.10, 3.11a-e, 3.12a-e, and 3.13
Meat and poultry processing only (all categories)	Sanitation	1.9, 1.10, 1.11, 1.16c-g, and 4.6
	Operations	1.16a, 1.16h, 1.16k, 1.16l, 3.1, 3.2, 3.3, 4.10, 4.11, and 4.13
	Equipment	1.17a-i
	Testing	1.18, 2.1, 2.2a-k, 2.3, 2.4a-l, 2.5, 2.6a-o, 2.7, 2.8a-k, 2.9, 2.10, 2.11a-c, and 2.12a-c

[1] Slaughter industries include plants that only slaughter plants (i.e. slaughter-only plants) and plants that both slaughter animals and process raw meat.
Slaughter survey questions: http://www.fsis.usda.gov/PDF/SRM_Survey_Slaughter_&_Processing_Plants.pdf/.
Processing-only plant questions: http://www.fsis.usda.gov/PDF/SRM_Survey_Meat_&_Poultry_Processing_Only_Plants.pdf/.

- If establishments indicated more cleaning shifts than production shifts (suggesting they may have misunderstood the question), we set the number of cleaning shifts equal to the number of production shifts.
- For cattle and hog slaughter plants, nine questions were used to construct the sanitation index, but eight of these questions were for further processing operations and one was for slaughter operations. A total of 94 cattle slaughter or hog slaughter plants did not further process, and thus only 1 question comprised their sanitation indexes.[18] This may have contributed to the lack of statistical significance for the sanitation index when compared across different categories of plants.

[18]For poultry slaughter, 83 plants did not further process. However, the sanitation index for these plants is based on six questions.

Appendix table B2

Slaughter industries: Mean number of types of animals slaughtered per industry quintile[1]

Plant type	Size percentiles (ranked by pounds of output)				
	0–19	20–39	40–59	60–79	80–99
	----------Mean number of animals slaughtered----------				
Cattle slaughter					
Cattle	701	563	927	4,034	498,258
Hogs	1,773	1,652	754	5,574	1,087
Other animals	1,370	831	524	2,805	5,991
Hog slaughter					
Hogs	4,429	5,676	2,343	15,195	1,475,331
Cattle	587	607	388	988	421
Other animals	1,129	620	307	8,168	164
Poultry slaughter					
Chickens	7,630,198	42,639,686	77,669,091	96,938,496	124,738,780
Turkeys	331,055	2,233,924	4,682,837	776,822	812,496
Other poultry	104,892	63	0	0	0

Note: Other poultry includes ducks, rabbits, geese, ratites, squab, and pigeons.
[1]Slaughter industries includes plants that only slaughter plants (i.e. slaughter-only plants) and plants that both slaughter animals and process raw meat.
Source: USDA, Economic Research Service and RTI calculations.

Appendix table B3

Slaughter industries: Mean product output shares per industry quintile[1]

Plant type	Size percentiles (ranked by pounds of output) 0–19	20–39	40–59	60–79	80–99
	Mean percent of output				
Cattle slaughter					
Raw product, not ground, primal cuts	28.5	45.9	59.5	74.7	84.6
Raw ground meat	41.0	37.7	24.9	10.4	13.9
Total processed product	30.5	16.4	15.6	14.9	1.5
Hog slaughter					
Raw product, not ground, primal cuts	29.9	41.5	52.4	72.3	79.1
Raw ground meat	36.3	40.9	29.9	12.2	10.4
Total processed product	33.8	17.6	17.7	15.5	10.5
Poultry slaughter					
Raw product, not ground	83.0	93.8	92.7	94.4	85.1
Raw ground poultry	11.5	4.9	1.4	2.2	8.8
Total processed product	5.4	1.4	5.9	3.4	6.1

[1] Slaughter industries includes plants that only slaughter plants (i.e., slaughter-only plants) and plants that both slaughter animals and process raw meat.
Source: USDA, Economic Research Service and RTI International calculations.

Appendix table B4

Processing-only industries: Mean product output shares per industry quintile

Plant type	Size percentiles (ranked by pounds of output) 0–19	20–39	40–59	60–79	80–99
	Mean percent of output				
RTE products					
Total raw product	8.3	13.7	8.8	4.8	1.1
Fully cooked, not shelf stable, such as bologna	53.1	60.7	61.6	57.5	84.5
Other processed product	38.6	25.6	29.6	37.7	14.4
NRTE products					
Raw product, not ground, primal cuts	22.8	55.1	58.8	33.4	27.6
Raw ground meat	32.4	24.0	28.2	39.5	31.9
Processed products	44.8	20.8	12.9	27.1	40.5
Ground beef					
Raw product, not ground, primal cuts	29.9	35.2	41.2	22.9	10.7
Raw ground meat	66.0	58.0	54.9	73.0	81.2
Processed products	4.1	6.8	3.9	4.1	8.1
Ground beef only	59.7	50.1	48.4	70.5	72.6

RTE=Ready To Eat.
NRTE=Not Ready To Eat.
Source: USDA, Economic Research Service and RTI calculations.