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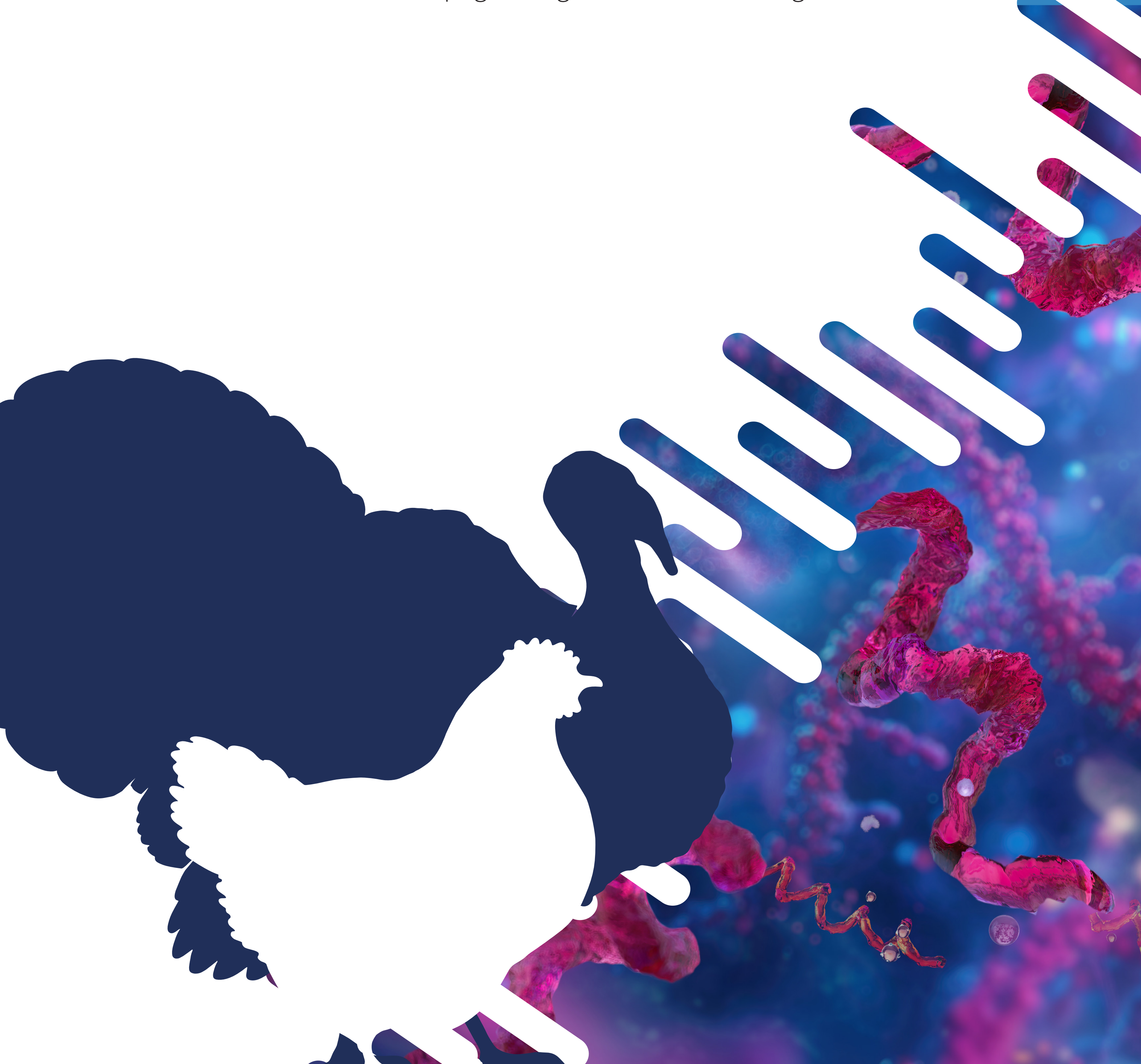
Signaling Food Safety: Pathogen Rates of Raw Poultry With Food Safety Certifications

Kar Lim, Yuqing Zheng, and Michael Ollinger



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Abstract

This study examines the relationship between private sector-led food safety certifications and pathogen detection rates in raw poultry products. The Global Food Safety Initiative (GFSI) establishes food safety benchmark programs to incentivize adherence to standardized practices. The analysis uses pathogen surveillance data from the USDA's Food Safety and Inspection Service from 592 raw poultry processing establishments, detecting *Campylobacter* and *Salmonella* from raw poultry products. These data are combined with certification status from three major GFSI-recognized programs for raw poultry: Safe Quality Food, Brand Reputation through Compliance Global Standard, and Food Safety System Certification 22000. Bivariate probit models are used to assess the association between certification status and pathogen detection rates. Certified products are, in general, statistically correlated with lower positive *Salmonella* detection rates. However, certified products do not consistently show lower *Campylobacter* detection rates. Only one of the examined certifications is statistically linked to reduced detection rates. Additionally, the correlation between individual certification and the pathogen detection rate varied. GFSI-recognized certifications may signal lower *Salmonella* detection rates, but not necessarily for other pathogens such as *Campylobacter* to stakeholders in the supply chain.

Keywords: Global Food Safety Initiative, *Salmonella*, *Campylobacter*, Foodborne Illness, Bivariate Probit

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A report summary from the Economic Research Service

Signaling Food Safety: Pathogen Rates of Raw Poultry With Food Safety Certifications

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Key Points

- Retailers and other stakeholders are increasingly relying on Global Food Safety Initiative (GFSI)-recognized certifications to facilitate food safety risk management. More than half of the poultry processing establishments in the United States are certified in 2023–24.
- This report compares *Salmonella* and *Campylobacter* detection rates between samples of certified and uncertified raw poultry products collected from 592 U.S. establishments.
- Certified poultry products are associated with significantly lower *Salmonella* detection rates.
- Certified products are not associated with consistently lower detection rates in *Campylobacter*.
- Differences across individual certification programs suggest that pathogen-specific outcomes may depend on the specific certification system.

Why Does This Matter?

The Global Food Safety Initiative (GFSI) has emerged as a leading private sector-led framework, which harmonizes private sector food safety standards across different certifiers. GFSI provides standards against which certification programs can be benchmarked. This function facilitates adherence to recognized food safety practices by food certifiers and food producers. Benchmarking promotes mutual recognition among different certifications, reducing the need for redundant or duplicate certifications.

Food producers and retailers rely on the certifications to signal adherence to food safety practices. However, little is known on whether the adherence to these certification programs results in a reduction of pathogens in raw poultry products. This report analyzes the relationship between GFSI-recognized certifications and pathogen detection rates in raw poultry products, focusing on three prominent certifications: Safe Quality Food (SQF), Brand Reputation through Compliance Global Standard (BRCGS), and Food Safety System Certification 22000 (FSSC 22000).

Understanding the impact of these certifications is valuable for public health and market efficiency. The cost of foodborne illnesses attributable to poultry is substantial in the United States. In addition, GFSI-recognized certifications also play a role in facilitating market access, standardizing food safety management systems, and enhancing consumer confidence. Such benefits to public health and market efficiency provide a basis for evaluating the role and value of these certifications.

We empirically assess whether products from establishments holding GFSI-recognized certifications exhibit different rates of *Salmonella* and *Campylobacter* detection compared to non-certified establishments. Findings from this analysis can inform policy discussions about the role and effectiveness of certification programs in safeguarding public health and guide resource allocation for industry stakeholders, policymakers, and consumer advocacy groups.

A Few More Details

This study combined data on pathogen testing results in raw poultry products from the USDA's Food Safety Inspection Service (FSIS) with certification status from certifiers, creating a unique dataset. The testing data encompassed 13,837 *Salmonella* and 7,519 *Campylobacter* tests, collected from 592 establishments between October 2023 and March 2024.

The primary outcome measure was the positive detection rate of *Salmonella* or *Campylobacter*. To assess the impact of certification on pathogen detection, the study employed the bivariate probit model. The model makes use of the fact that *Salmonella* and *Campylobacter* detection tests are often conducted in tandem on individual samples. Separate probit models were also estimated for each pathogen. Lastly, we explored how the association might change according to the size of the establishments and the types of products.

Signaling Food Safety: Pathogen Rates of Raw Poultry With Food Safety Certifications

Introduction

Private sector-led food safety certification programs—such as the Global Food Safety Initiative (GFSI) recognized certifications—have been viewed as promising food safety tools. Rao et al. (2021), for instance, argued that private food safety standards “have become an important governance mechanism in contemporary food safety chains.” GFSI benchmarks against a set of food safety principles, thereby standardizing various individual certifications. Such certifications are now widespread as they have become a requirement for suppliers to access high-value food markets (Fagotto, 2014). Nevertheless, the reliability of such certifications is not fully understood, stemming from the lack of external accountability in the form of third-party verified benefits (Fuchs et al., 2011). This report compares the pathogen detection rates in raw poultry products from establishments with GFSI-recognized food safety certifications to those without. The goal is to provide empirical evidence on the efficacy of these voluntary measures.

Ensuring food safety has involved a combination of government food safety performance standards and industry initiatives. While public food safety performance standards establish a baseline, the industry often favors voluntary measures, arguing that they provide flexibility and foster innovation, especially given the complex modern food supply chain (Lin, 2014).

GFSI-recognized certifications—such as Safe Quality Food (SQF), Brand Reputation through Compliance Global Standard (BRCGS), Food Safety System Certification 22000 (FSSC), and others—have become a prominent form of voluntary industry effort (Wang, 2021; Hu et al., 2023). To gain the certifications, producers must adhere to the defined safety principles and protocols, including the implementation of food safety programs and guidelines, and undergo independent third-party audits.

If GFSI-recognized certifications are proven effective, they could be valuable for food safety management. This study analyzes the rates of pathogen detection of various GFSI-recognized certifications by examining associations between *Campylobacter* and *Salmonella* detection rates among raw poultry producers with and without these certifications.

Background

Food safety is critical for consumers, agribusinesses, and public policy. Annually, foodborne illnesses affect approximately 48 million people in the United States, causing significant morbidity, mortality, and an economic burden (Hoffmann et al., 2015). USDA, Economic Research Service (ERS) estimates the costs resulting from foodborne pathogens in the United States to be $74.7 billion in 2023 dollars (USDA, ERS, 2025). *Salmonella* and *Campylobacter* are two major foodborne pathogens in the United States, where nontyphoidal *Salmonella* and *Campylobacter* illnesses are estimated to cost, respectively, about $17.1 billion and $11.3 billion annually (USDA, ERS, 2025). Scharff (2020) estimated these bacteria in poultry contributed around $9.7 billion of economic loss in the United States annually, based on data from 1998 to 2007.

The estimated cost of foodborne illness represents a significant economic burden, considering that U.S. poultry sales were $76.9 billion in 2022 (USDA, ERS, 2023). This cost underscores the pressing need to mitigate foodborne illnesses. The Healthy People 2030 Initiative incorporates 21 objectives that are specifically targeted at foodborne illness reduction (U.S. Department of Health and Human Services, n.d.).

USDA, Food Safety and Inspection Service (FSIS) samples raw poultry products for *Campylobacter* and *Salmonella* tests (USDA, FSIS, 1996; 2021a). Both pathogens have seen reductions in detection rates in raw poultry carcasses and parts, likely the combined results of regulatory requirements, stricter demand from retailers, and increased applications of safer production protocols (USDA, FSIS, 2021b; Ollinger et al., 2024; Williams et al., 2021; Williams et al., 2020). For instance, USDA, FSIS reported the detection rate of *Salmonella* in young chicken carcasses at 16.3 percent in 2005, which dropped to 3.5 percent in the 12 months leading up to April 2025 (USDA, FSIS, 2025; USDA, FSIS, 2021b). Similarly, the detection rate of *Campylobacter* in young chicken carcasses dropped from a baseline rate of 88.2 percent in 1994–95 to 25.41 percent in the 12 months leading up to April 2025 (USDA, FSIS, 2025; Williams et al., 2021).

In 2006, USDA, FSIS proposed disclosing the *Salmonella* test of chicken-carcass processing establishments. Specifically, establishments are placed into one of three categories. The best performing establishments are assigned to Category 1 and the worst performing establishments, which failed to meet the standard, are assigned to Category 3. In 2008, the policy was adopted with the categories disclosed on the USDA, FSIS website (Federal Register, 2008). A sharp reduction in overall *Salmonella* rates followed the implementation of the disclosure policy, but it had negligible impacts on low-performing establishments (Ollinger & Bovay, 2020). To further reduce *Salmonella* rates, USDA, FSIS may require establishments in Category 3 to implement corrective actions. Under HACCP, establishments are required to perform corrective actions whenever their system is not functioning as intended—for example, when control of a hazard is not met—and USDA, FSIS verifies that these corrective actions are effective (USDA, FSIS, 2021a).

Conceptually, food safety can be defined as an economic good with unobserved characteristics the consumer cannot verify (Caswell & Mojduszka, 1996; Lancaster, 1966). Many pathogens and contaminants are not detectable by consumers at the point of purchase, underscoring the importance of preventive food safety measures and regulatory oversight (Roberts & Scharff, 2018). Additionally, tracing the source of foodborne illness is challenging (Roberts & Scharff, 2018). Thus, value chain intermediaries, such as retailers and foodservice, may disproportionately bear the cost of food safety incidents.

Products are often purchased repeatedly, relying heavily on consumer loyalty and trust. Food safety issues linked to a single product can have a spillover effect, negatively impacting the perception of other products carried by the same brand or retailer (Polinsky & Shavell, 2009), or related products by other companies. A pertinent example is the 2017–18 E. coli outbreak in lettuce. Astill et al. (2020) found that production seasonality in lettuce complicated identification of the source of the outbreak. Spalding et al. (2023) found that affected shippers, processors, and retailers suffered major losses, resulting from reduced consumer demand that persisted after the incident. Recalls related to food safety concerns can trigger a decline in consumer demand for the affected products, leading to significant revenue losses for retailers (Yim & Katare, 2023; Taylor et al., 2016). These factors have amplified the importance of certifications as a risk management tool for food retailers and related agribusinesses.

Private food safety certifications, such as GFSI-recognized programs, are positioned as market-based solutions to address information gaps in food safety. These certifications may enhance food safety outcomes and incentivize producers to uphold higher standards. However, the direct correlation between private sector certifications and improved food safety remains unknown.

The U.S. food supply is widely regarded as one of the safest. Consequently, with relatively limited opportunities for further improvement, the question arises whether additional measures—such as certification—offer diminishing returns. Determining whether GFSI-recognized certifications meaningfully reduce foodborne illness risks, or merely add complexity and cost, is an important consideration for agribusinesses.

GFSI was established in May 2000 by the Consumer Goods Forum, a coalition of major retailers and food manufacturers. GFSI maintains that it is "strengthening and harmonizing food safety systems," with a goal "to help ensure safe food for people everywhere" (Global Food Safety Initiative, n.d.). GFSI does not provide certifications directly. Instead, it fosters harmonization by creating benchmarked requirements that third-party certification programs—such as SQF, BRCGS, and FSSC 22000—must meet. Third-party certification programs evaluate the food safety management systems of establishments against GFSI benchmarks, enabling alignment of firm-specific standards with industry standards. Food producers and manufacturers may choose to obtain certification voluntarily, if doing so fits their overall objective.

GFSI benchmark requirements have three components. First, certification programs must implement Hazard Analysis and Critical Control Points (HACCP). HACCP is a well-established protocol that identifies hazards and the associated critical control points (or processes) where hazards, including pathogens, can be controlled or prevented. Second, certification programs must have Food Safety Management Systems (FSM) demonstrated through resource allocation and support for continuous improvement, internal and external communication protocols, and emergency preparedness plans. And lastly, the benchmark requires additional programs that are applicable to the particular industry, such as Good Industry Practices (GIP), Good Manufacturing Practices (GMP), or Good Agricultural Practices (GAP), which complement HACCP (Global Food Safety Initiative, 2020; Keener, n.d.). However, the requirements do not contain specific pathogen target levels on final products.

These benchmarks standardize certification programs, fostering mutual recognition among various schemes. While absolute equivalence is not guaranteed, it promotes harmonization and reduces the need for redundant audits. This reflects GFSI's objective to enable "once certified, recognized everywhere" (Global Food Safety Initiative, n.d.). Therefore, the benchmark standards are the common thread among various GFSI-recognized programs.

Each program differs in implementation and scope, such as the frequency of audits, grading systems, and industry-specific guidelines. For example, BRCGS requires an annual audit and an unannounced audit at least once every 3 years (BRCGS, 2020); FSSC 22000 requires an annual surveillance audit to ensure the outlined protocols are carried out and a recertification audit every 3 years (Food Safety System Certification 22000, 2017); SQF requires an annual audit, with 6-month surveillance audits for establishments with low scores (Safe Quality Food, 2020). Individual certification may also contain specific guidelines to sectors of the food industry (National Sanitation Foundation, 2025).

All GFSI-recognized certifications must meet other regulatory guidelines required by USDA, FSIS. Specifically, the benchmarking requirements state that "Procedures shall be established, implemented, and maintained to ensure compliance with applicable legislation (both countries of production and intended sale)" (Global Food Safety Initiative, 2024). Thus, USDA, FSIS guidelines are mandatory for all establishments, regardless of certification status.

In the context of raw poultry products, USDA, FSIS mandates that establishments must maintain and follow written Sanitation Standard Operating Procedures (SSOP) and HACCP plans. An establishment's HACCP plan may be deemed inadequate if it does not meet HACCP acquirements or if establishment personnel fail to perform the task specified in the plan, as outlined in 9 CFR 417.6 (USDA, FSIS, 1996). These plans overlap with the requirements of GFSI benchmarks related to animal primary conversion, such as slaughtering and partitioning (Global Food Safety Initiative, 2024).

Lastly, GMP, SSOP, and HACCP also include sanitation procedures aimed at facilitating a controlled environment for production. These plans and protocols often target similar areas, such as temperature control for storage, cleaning and disinfection of work areas, and equipment sanitation. For example, with regards to cross-contamination pathogenic risk, the GMP 4.1 requirement of GFSI states that "Product Contamination Risk and Segregation Procedures shall be established, implemented, and maintained to prevent or minimize risk of contamination and cross-contamination of purchased materials, work in progress, rework, packaging, and finished product covering all aspects of food safety" (Global Food Safety Initiative, 2024); USDA, FSIS requires establishments' HACCP plans to consider the risk of cross-contamination and outgrowth "for processing, storage, thawing, and any step where conditions may allow proliferation of pathogens" (USDA, FSIS, 2020).

USDA, FSIS maintains product-specific compliance rates for *Salmonella* pertaining to raw poultry. Failure to meet the standards may result in a publicly posted Category 3 rating and USDA, FSIS verification of establishment corrective actions (USDA, FSIS, 2021a). GFSI benchmarking does not set specific pathogen detection targets on products. However, certifications may set pathogen levels on production environment to reduce the risk of contaminated products (Food Safety System Certification 22000, 2023). Despite the differences in scope, pathogen control is a general goal of the HACCP protocol—a key requirement of both USDA, FSIS and GFSI.

In the United States, GFSI-recognized certifications are primarily used in business-to-business settings. Retailers require upstream food producers to be certified. By doing so, these certifications serve two key purposes: (1) they allow retailers to influence practices of upstream producers; and (2) they allow retailers to demonstrate their commitment to food safety. Hence, these certifications signal food safety mostly to business buyers; the information is infrequently conveyed to consumers (Hu et al., 2023).

Crandall et al. (2017) found that most certified producers perceived GFSI as beneficial, allowing buyers to identify foods of higher food safety and spur demand. Producers also find that certification leads to benefits such as being more prepared for regulatory change, improved regulatory compliance, and improved documentation. Additionally, producers pursue certification for market access for exports, liability protection, and competitive advantage stemming from product differentiation (Bar & Zheng, 2019; Global Food Safety Initiative, 2011; Hu et al., 2023).

Nevertheless, Crandall et al. (2017) reported that customer demand is the primary reason for producers to seek certification, as opposed to using the certifications for continuous business improvement, documentation, or improving operation efficiency. They also reported that certification entails notable investment in staff training, time, internal audits, and capital costs. Given the increasing adoption of certifications, the benefits of certifications appear to outweigh the costs for many producers (Bar & Zheng, 2019; Crandall et al., 2017; Hu et al., 2023).

Although harmonization establishes a benchmark, there may be differences in food safety outcomes between individual certification programs. While the plans, precautions, and audits specified in GFSI requirements may be beneficial, questions remain about the effectiveness in GFSI in terms of measurable food safety outcomes (Bar & Zheng, 2019; Hu et al., 2023; Muse & Amiri, 2024; Wang, 2021; Zheng & Bar, 2023). Roberts and Scharff (2018) argue that even with Federal food safety standards in place, producers retain the discretion to vary their investments. Thus, producers may also be discretionary in their efforts to gain and maintain the certifications.

Several empirical studies support Roberts and Scharff's argument. Bovay (2024) found that while the disclosure of food safety performance appears to induce higher food safety performances from producers overall, some low performance persists despite stringent disclosure thresholds. Ollinger et al. (2024) observed that establishments strategically adjusted food safety practices according to the frequency of USDA, FSIS sampling. Dynamics between producers and certification bodies might play a role in the complexity of maintaining full objectivity in the auditing process, as suggested by studies examining auditor selection and competitions within certification markets (Bar & Zheng, 2019; Zheng & Bar, 2023). Muse and Amiri (2024) suggest that certifications may suffer from prescribing "generic" and "frivolous" requirements while lacking demonstrative evidence to quantify food safety improvements. Retailers and restaurants may also impose additional requirements such as targets for pathogens or additional audits (Costco Wholesale, 2023; McDonald's, 2025; Walmart, n.d.); this suggests that the certifications do not solely satisfy retailers' food safety expectations. Previous studies—focusing on different products and periods—have reported mixed results about the food safety outcomes of the certifications (Wang, 2023; Hu, 2022). These critical views highlight the need to evaluate the association between certifications and desirable food safety outcomes.

This study investigates pathogen detection rates in raw poultry products by certification status, utilizing publicly available test samples conducted by USDA, FSIS. Our objective is to compare the *Campylobacter* and *Salmonella* detection rates between certified and uncertified products. Within the scope of our research, we focus on three GFSI-recognized certificates: Safe Quality Food (SQF), Brand Reputation through Compliance Global Standard (BRCGS), and Food Safety System Certification 22000 (FSSC), which all apply to raw poultry products.

The certifications do not directly specify targeted levels of pathogen mitigation on finished products. Rather, they are a framework that facilitate adherence to principles to promote pathogen reductions. Nevertheless, given the wide acceptance of GFSI and its explicit goal to "help ensure safe food for everyone" (Global Food Safety Initiative, n.d.), whether the certification is associated with better quantifiable food safety metrics, such as pathogen levels, is a pertinent question (Muse & Amiri 2024). This report examines the role of the certifications as a process validation mechanism, addressing in particular how agribusinesses and policymakers may consider GFSI-recognized certifications.

Our analysis is cross-sectional rather than longitudinal (i.e., comparison of pathogen rates among establishments before and after certification). Given the data constraint, our study does not investigate if certifications causally lead to lower pathogen risks. Rather, we assess whether certified products exhibit differences in pathogen detection rates compared to uncertified ones. While a longitudinal approach could provide further insights into certification impact over time, our study offers an initial assessment of certification's association with pathogen detection rates. This distinction is important as this report lays a foundation for future studies on the causal relationship between certification and pathogen rates, which tackles the effectiveness of the certifications as a direct intervention tool in terms of pathogen controls.

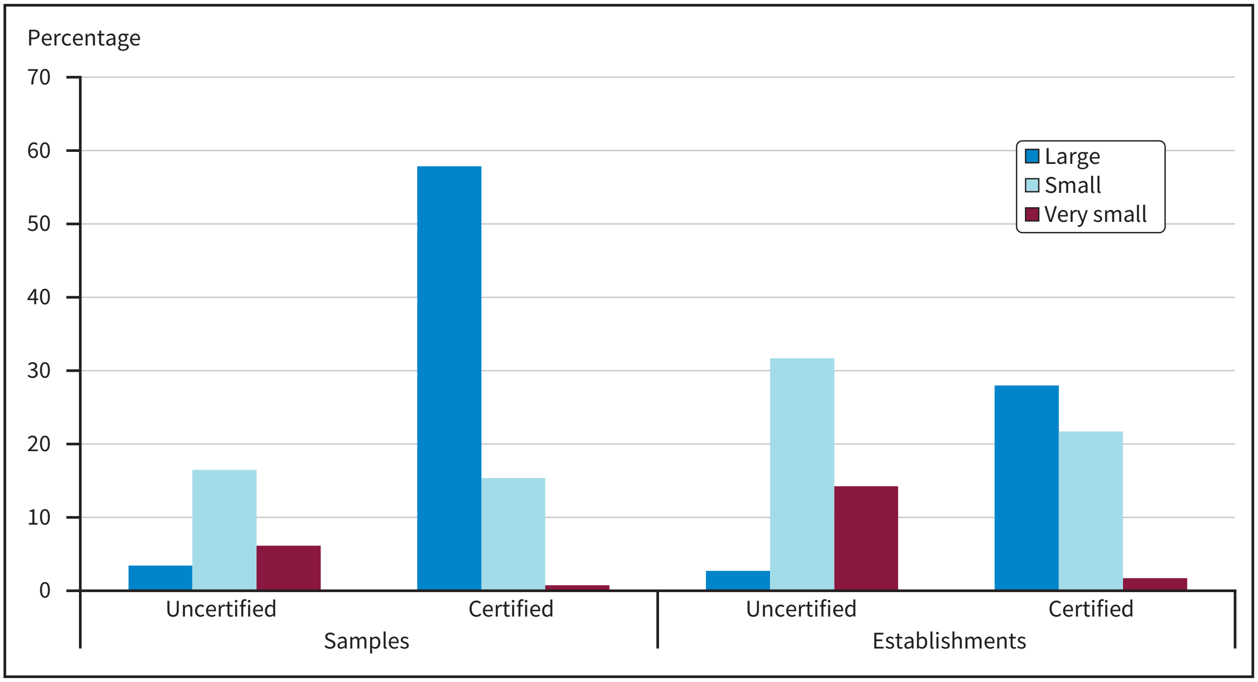
Data and Methods

The Raw Poultry Sampling program dataset encompasses 13,837 samples tested for *Salmonella* and 7,519 samples tested for *Campylobacter*, collected between October 2023 and March 2024—the latest available data during the collection stage of this study. The data are drawn from 592 raw poultry processing establishments (USDA, FSIS, 2024). USDA, FSIS samples all establishments that fit the sampling profile, which is based on production volumes, product types, and other factors (USDA, FSIS, 2021). The sampling is designed to select a subset of all eligible products across different establishments. Almost all the samples are tested for *Salmonella*. However, only about half of the samples are also tested for *Campylobacter*.

While earlier sampling data are available, matching certification status is unavailable. The lack of complete panel data prevents effective determinations of within-establishment effects of certification. Thus, our analysis examines whether certifications are associated (or correlated) with a different *Salmonella* and *Campylobacter* detection rates in poultry products in the 6-month sampling period. We note that the association indicates certification may lead to lower pathogen rates. But the association, by itself, does not guarantee better pathogen detection rates or that certifications cause improvements. We obtain the certification status of establishments from the certifiers' public online directories. In total, 73 percent of the samples were from certified establishments. BRCGS-certified establishments account for 56 percent of the total sample, while SQF-certified establishments represent approximately 18 percent. In contrast, only 0.3 percent of the sample comprises FSSC-certified establishments, drawn from two establishments (figure 1). Due to this limited representation, the results related to FSSC should be interpreted with caution as they are likely influenced by establishment-specific factors.

More than half of the samples (58 percent) are collected from certified large establishments. This reflects the fact that large establishments, which often produce more than one category of products, are sampled more frequently. The certification rate drops as size decreases. Only slightly more than half of the samples collected from small establishments are certified. Lastly, only about one-tenth of the samples collected from very small establishments are certified. The unequal distribution highlights the need for regression analysis, as univariate tests may confound the effects from other factors with the effects from certifications.

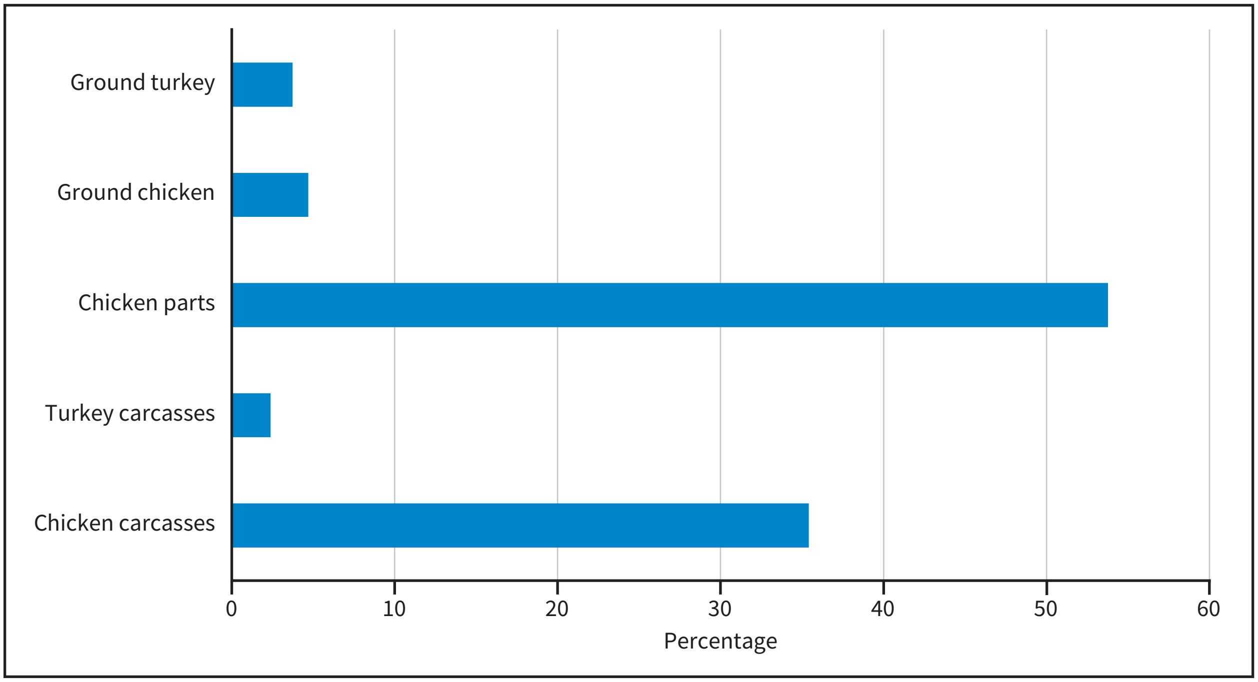
Figure 1
The distribution of samples and establishments by certification status



Source: USDA, Economic Research Service calculations based on USDA, Food Safety and Inspection Service, Quarterly Sampling Reports on *Salmonella* and *Campylobacter*, 2024.

The pathogen test data are divided into five categories (HACCP projects) (figure 2). Namely, 35 percent are young chicken carcasses, 2 percent are young turkey carcasses, 54 percent are chicken parts (legs, breasts, and wings), 5 percent are ground and other comminuted chicken (non-mechanical separated), and 4 percent are ground and comminuted turkey (non-mechanical separated). Follow-up tests, which are intended to gauge the effectiveness of corrective actions, are excluded from the analysis because they may subject to different sampling criteria.

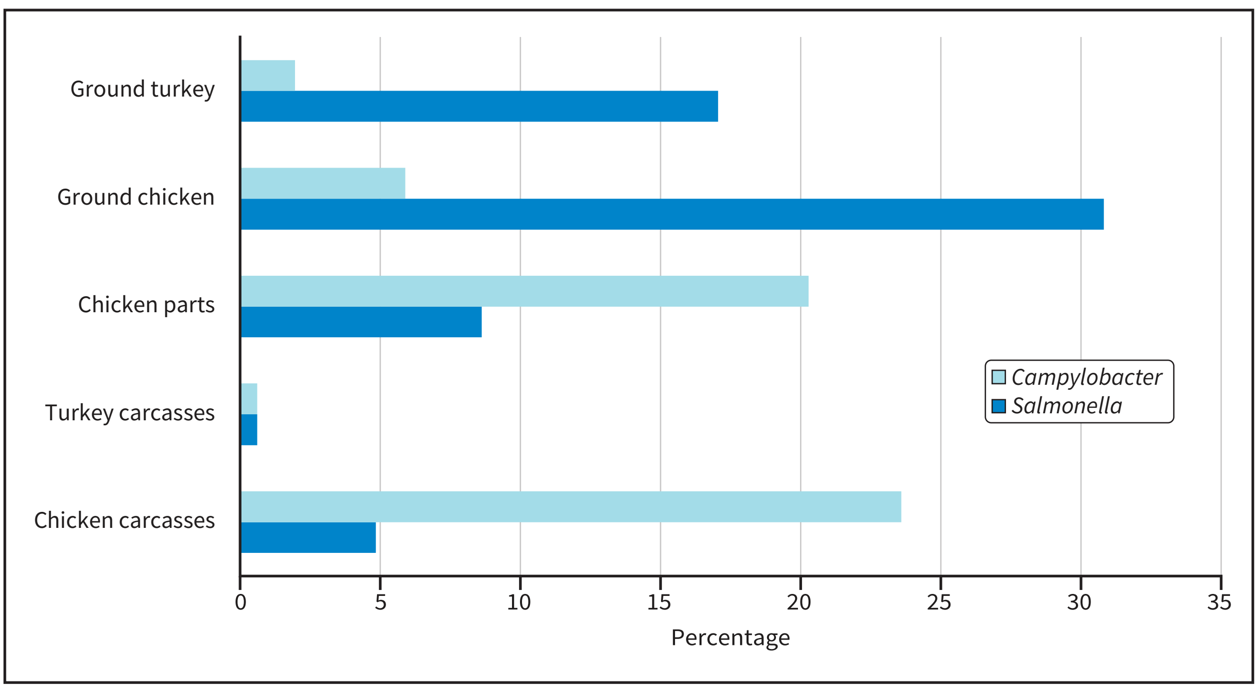
Figure 2
Distribution of samples by product type



Note: Ground refers to ground and comminuted products.

Source: USDA, Economic Research Service calculations based on USDA, Food Safety and Inspection Service, Quarterly Sampling Reports on *Salmonella* and *Campylobacter*, 2024).

Figure 3
Positive rates of *Campylobacter* and *Salmonella* by product type



Note: Ground refers to ground and comminuted products.

Source: USDA, Economic Research Service calculations based on USDA, Food Safety and Inspection Service, Quarterly Sampling Reports on *Salmonella* and *Campylobacter*, 2024.

The overall detection rates for *Salmonella* and *Campylobacter* are 8.4 percent and 18 percent, respectively, for all product types. Nevertheless, the rates differ significantly by product type. Ground and comminuted poultry products carry a higher *Salmonella* risk, ranging from 31 percent for chicken to 17 percent for turkey (figure 3). In contrast, the highest positive rates for *Campylobacter* are associated with young chicken carcasses at 23 percent. Both *Salmonella* and *Campylobacter* are part of the natural microbiota in poultry. Differences in processing methods and microbial ecology may explain the difference in detection rates between chicken and turkey (Fearnley & Rodgers, 2023). Some antimicrobial treatments used in processing plants may be more effective against *Salmonella* than *Campylobacter* (Thames & Sukumaran, 2020). Lastly, grinding poultry products impact pathogens differently. Grinding exposes *Campylobacter* to oxygen, which inhibits its survival; but *Salmonella* may spread more evenly throughout the product (Keener et al., 2004).

Additionally, USDA, FSIS data demonstrates that an establishment's size can be a factor in the positive rates of *Salmonella* and *Campylobacter*. In particular, large establishments are observed to have lower positive tests for several products (USDA, FSIS, 2024).[1] These variations in positive rates highlight the need to account for other factors like establishment size and product type in our analysis. About half of all and most large establishments are certified (appendix A). Appendices B and C provide more detailed statistics. The pathogens rates appear highly complex and are dependent on several factors, including product types, certifications, and the size of establishments.

Our main analysis relies on the bivariate probit model, which accounts for potential correlations between the *Salmonella* and *Campylobacter* tests. As the tests are performed on common samples, unobserved characteristics—such as management philosophy, sourcing, and other plant-specific characteristics—are likely correlated. A positive *Salmonella* test may affect the probability of a given sample testing positive for *Campylobacter*.

A main feature of the bivariate probit model is the estimation of the joint probability that a certified product is more or less likely to test negative for both *Salmonella* and *Campylobacter*. The bivariate probit model is specified as:

$$y_1^* = X_1\beta_1 + \epsilon_1 \qquad (1)$$

$$y_2^* = X_2\beta_2 + \epsilon_2$$

The subscripts 1 and 2 denote *Salmonella* and *Campylobacter* tests, respectively. The observed binary outcomes are determined by:

$$y_1 = 1 \text{ if } y_1^* > 0, 0 \textit{ otherwise} \qquad (2)$$

$$y_2 = 1 \text{ if } y_2^* > 0, 0 \textit{ otherwise}$$

y_i^* are latent variables that represent the underlying continuous measure of *Salmonella* or *Campylobacter*. The observed binary outcomes (y_i = 1 for positive detection, y_i = 0 for negative detection) are determined when these latent variables exceed a threshold of 0. The model estimates the

[1] Antle (2000) showed that food safety in meat and poultry industries was associated with per capita income, the ratio of nonproduction workers (managers) to production workers, and product mix. Thus, it is a higher ratio of managers, including quality control personnel, to production workers that encourage lower *Salmonella* rates. Large slaughter establishments process more chickens with proportionately fewer production workers due to economies of scale. These lower production costs enable investment in food safety, including quality control personnel, lowering *Salmonella* rates. Large establishments have more output, a larger proportion of managers to production workers, and more total employees than smaller establishments.

β_i coefficients to align the latent variables with the observed outcomes, such that the conditions outlined in equation 2 are met.

Observed factors are represented by X_1 and X_2. In this application, X_1 and X_2 are identical sets of dummy variables representing: (1) the types of certifications associated with the establishment—BRCGS, SQF, and FSSC—each modeled explicitly to illustrate the potential difference between each of the certification and (2) the types of the sampling program (or products), which are young chicken carcasses; young turkey carcasses; chicken parts–legs, breasts, and wings; ground and other comminuted chicken; and ground and other comminuted turkey. And (3) the size of the plants according to USDA, FSIS delineation provided in the Meat, Poultry, and Egg Product Inspection Directory. Large establishments have 500 or more employees; those establishments with fewer employees are categorized as small or very small establishments (USDA, FSIS, 2016). The error terms are assumed to follow the correlated standard normal distribution.[2]

As the bivariate probit model accounts for correlated error terms, it excludes samples that were not tested for both *Salmonella* and *Campylobacter*. As a result, the sample size of the bivariate probit model decreases to 7,516 tests. Given this tradeoff, we also estimate equations 1 and 2 individually with probit models.

Because the magnitude of parameter estimates in equation 1 is not directly interpretable (Greene, 2008), we derive average marginal effect estimates and average joint effect estimates. The average marginal effects measure the percentage-point differences between certified and uncertified products in *Salmonella* and *Campylobacter* detection rates; for instance, the difference in *Salmonella* detection rates between uncertified products and BRCGS-certified products. The joint marginal effect estimates how likely the certified products are to test negative on both the *Salmonella* and *Campylobacter* tests; for instance, the difference in the likelihood for BRCGS-certified products to test negative for both pathogens compared to uncertified products. The marginal and joint effects illustrate different perspectives on whether the certifications are associated with lower risks.

Lastly, a deeper dive into the potentially heterogenous effects of certification by establishment size and product types is performed. We augment the bivariate probit model to include interactions between certification and establishment size and product types. The estimated marginal effects of the interaction terms could further illuminate the properties of GFSI-recognized certifications. In this model, the three individual certifications are aggregated to avoid the pitfalls of over-fitting from having too many interaction terms. The estimated coefficients are translated into average marginal effects for interpretation (Ai & Norton, 2003).

The data and methodology used in this report differ from previous studies. This report focuses on poultry products, whereas Hu (2022) and Wang (2023) covered a wider range of products. Notably, the previous studies do not control for the types of poultry products and the establishment size, which are risk factors of *Salmonella* and *Campylobacter* (USDA, FSIS, 2024). The omission may cause biased estimates (Greene, 2008). Second, this report uses more recent data, which may better reflect the present outlook. Lastly, the bivariate probit provides a novel perspective on whether the certification is associated with the test outcome of both *Salmonella* and *Campylobacter*.

[2] The bivariate probit models are estimated with the maximum likelihood method. Details of the maximum likelihood function as well as technical aspects of the estimator are discussed in Greene (2008).

Results

Overall, the estimates from the bivariate and individual probit models fit expectations (as reflected in figure 3). Ground and comminuted chicken and turkey have the highest positive *Salmonella* detection rates, but turkey carcasses have significantly lower *Salmonella* detection rates (appendix D.). In contrast, chicken carcasses have the highest rates for *Campylobacter*. Whereas turkey products, both in carcasses and ground/comminuted forms, have lower positive rates. Products from large establishments are found to have lower positive test rates for *Campylobacter* as well. These results align with observations from the Quarterly Sampling Reports on *Salmonella* and *Campylobacter* (USDA, FSIS, 2024).

Bivariate Probit Model

Table 1
Parameter estimates from the bivariate probit model of the detection of *Salmonella* and *Campylobacter*

	Salmonella		***Campylobacter***	
	Estimates	**[S.E.]**	**Estimates**	**[S.E.]**
Certifier [Base: uncertified]				
Safe Quality Food (SQF)	-0.41***	[0.10]	-0.06	[0.12]
Food Safety System Certification (FSSC)	-0.68	[0.52]	-0.92**	[0.41]
Brand Reputation through Compliance Global Standard (BRCGS)	-0.29***	[0.09]	-0.08	[0.09]
Control variables				
Large establishments [Base: very small and small establishments]	0	[0.07]	-0.16*	[0.08]
Type [Base: chicken carcasses]				
Turkey carcasses	-0.83***	[0.25]	-1.82***	[0.25]
Chicken parts	0.22***	[0.06]	-0.16***	[0.05]
Ground chicken	1.15***	[0.11]	-0.95***	[0.24]
Ground turkey	0.77***	[0.16]	-1.39***	[0.19]
Constant	-1.44***	[0.09]	-0.54***	[0.07]
ρ	0.23***	[0.03]		
Sample size	7,516			
Akaike information criteria	10,766.95			
Bayesian information criteria	10,898.52			
Log-likelihood	-5,364.48			

S.E. = standard error.

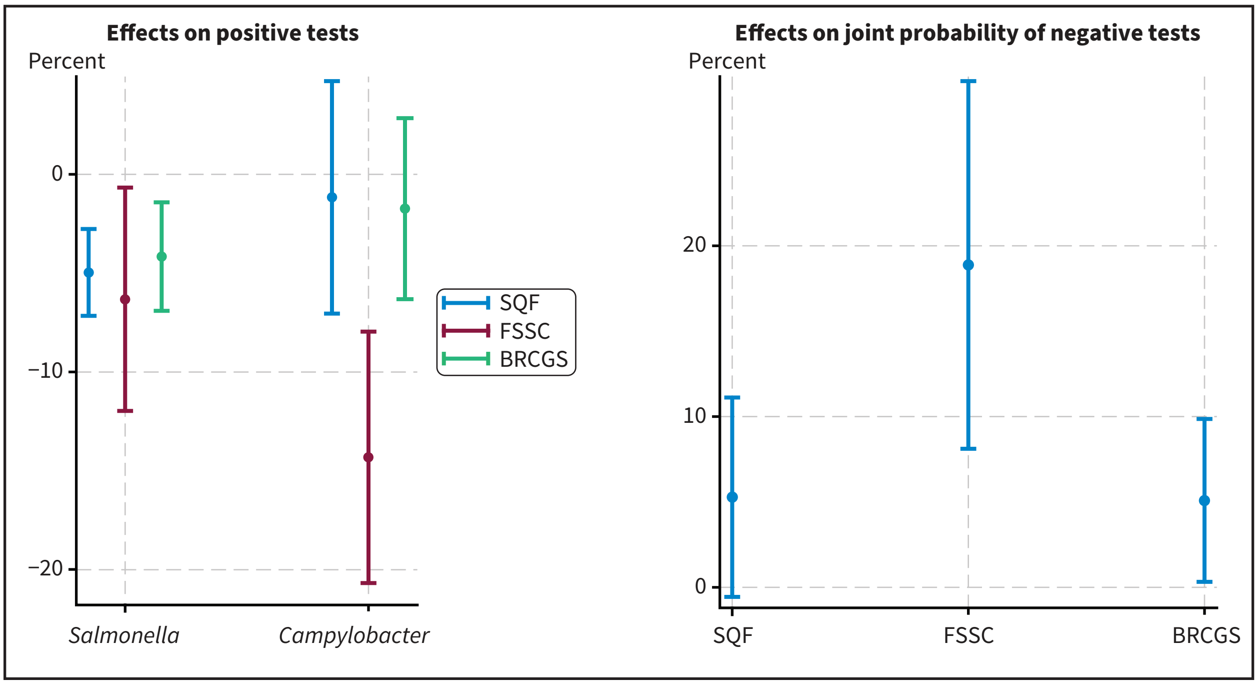
Note: ***, **, and * represent significant levels of 1 percent, 5 percent, and 10 percent. Ground refers to ground and comminuted products.

Source: USDA, Economic Research Service calculations based on USDA, Food Safety and Inspection Service data and certifiers' directory.

Table 1 contains the estimates from the bivariate probit model, with results specific to the *Salmonella* test on the left and results specific to the *Campylobacter* test on the right. The correlation in the error term ρ is 0.23 and statistically significant (Wald test of $\rho = 0$: $p < 0.01$), indicating that some unobserved factors simultaneously affect both the *Salmonella* and *Campylobacter* tests. Failure to account for the correlation in the error term may lead to biased or inefficient estimates (Greene, 2008). Thus, bivariate probit model is preferred over the probit model.

Figure 4 presents the difference in *Salmonella* and *Campylobacter* detection rates of certified products compared to uncertified products. Certified products are associated with equal or lower pathogen detection rates than uncertified products in general, denoted by the negative estimates in the first and second columns. Nevertheless, these relationships are only statistically significant for some of the certifications. For example, all three certifications are statistically significantly associated with lower detection of *Salmonella,*[3] while FSSC is the only certification associated with lower detection of *Campylobacter.* Not all the certifications are associated with lower detection rates across both pathogens. Thus, certified products are at least as safe as uncertified ones but are not necessarily always safer.

Figure 4
Average marginal and joint effects of certifications on the detection of *Salmonella* and *Campylobacter*, based on the bivariate probit model



SQF = Safe Quality Food; FSSC = Food Safety System Certification; BRCGS = Brand Reputation through Compliance Global Standard.

Source: USDA, Economic Research Service calculations based on USDA, Food Safety and Inspection Service data and certifiers' directory.

Compared to uncertified poultry products, products with the certifications are estimated to be 4–6 percentage points (all with $p<0.05$ or lower) less likely to test positive for *Salmonella,* on average and holding other factors constant. The magnitude of reduction is notable given the average rate of 8.4 percent for *Salmonella* detection.

[3] The average marginal effects of FSSC on *Salmonella* detection is statistically significant while the coefficient associated with FSSC in the bivariate probit model is not. This is because the calculation of average marginal effects involves the correlation in error term (Greene, 2008). Given that the correlation is significant, the standard error of the average marginal effect is narrowed.

Products with the FSSC certification are possibly associated with a lower detection rate for *Campylobacter*. The average marginal effect of the reduction is estimated to be 14 percent ($p<0.01$) (figure 4). For reference, uncertified products have a *Campylobacter* detection rate of 20.5 percent. Nevertheless, SQF and BRCGS are not associated with a statistically significant reduction in *Campylobacter* detection. While the estimates associated with the two certifications are negative, the estimated average effects are small, which may contribute to their lack of statistical significance. These variations suggest that not all certifications may be effective in mitigating *Campylobacter*.

Certified products are more likely to test jointly negative for the bacteria (figure 4). Both the SQF and BRCGS certifications are associated with products being about 5 percentage points more likely to test negative for both bacteria than uncertified products ($p=0.08$ and $p=0.04$, respectively). The model estimates that FSSC-certified products are about 19 percentage points ($p< 0.01$) more likely to test negative for both pathogens, albeit with a smaller sample size.[4]

For reference, about 69 percent of the tested products from uncertified establishments test negative for both pathogens. Certified establishments are modestly more likely to produce products that are negative for both pathogens. Even so, safety-conscious buyers may find certified products to be attractive options. The statistical significance of ρ suggests that certified establishments may be more likely to implement effective protocols that simultaneously control for both pathogens.

Probit Models for Comparison

For comparisons, the estimates of the individual probit models are presented in appendix E. In the *Salmonella* model, the coefficients associated with SQF and BRCGS are negative and statistically significant, as with the bivariate probit model. The average marginal effects show that SQF and BRCGS certified products are about 4 percent less likely to test positive for *Salmonella*, which is similar to the bivariate probit model (appendix F). The marginal effect for FSSC is not statistically significant.

Likewise, in the *Campylobacter* model, the estimates follow the bivariate probit model closely. The coefficient associated with FSSC is negative and statistically significant, while the coefficients associated with BRCGS and SQF are not statistically significant. FSSC-certified products may be 14 percent less likely to test positive for *Campylobacter*, which reflects the prior findings. These findings generally mirror the bivariate probit model.

Bivariate Probit Model With Interaction Terms

The purpose of the model is to capture the heterogenous effect of certification on detection across establishment size and product type. This supplements the bivariate probit model.

The model converged with a pseudo-likelihood of -5,311.38 (appendix G). The marginal effects, based on the estimated coefficients, show that certification varies by product and establishment size (appendix H).

[4] Twenty of the 22 samples collected from FSSC-certified establishments tested negative for both pathogens.

The certifications are associated with a higher reduction in positive rates for whole chicken carcasses. On average, certified chicken carcasses are 8 percent ($p<0.01$) and 7.8 percent ($p=0.097$) less likely to test positive for *Salmonella* and *Campylobacter*, on average. Certified chicken parts are 5.1 percent ($p=0.64$) less likely to test positive for *Salmonella*, on average. Additionally, certifications are associated with 7 percent ($p<0.01$) and 6.2 percent ($p=0.03$) reductions for very small/small establishments, respectively, in the likelihood of positive *Salmonella* and *Campylobacter* tests.

When products and establishment size are both accounted for in the model (appendix I), the certifications are associated with 15.7 percent ($p=0.01$) lower positive *Campylobacter* rates for chicken carcasses produced by very small/small establishments. In contrast, the certifications are associated with lower positive *Salmonella* detection rates for chicken carcasses (14.1 percent; $p=0.04$) and ground chicken (15.5 percent, $p=0.08$) produced by very small/and small establishments. Food certifications are also associated with lower positive rates of *Salmonella* detection (4 percent, $p=0.06$) for chicken carcasses produced by large establishments.

Thus, the effect of the certifications varies across product and establishment types. In particular, the reductions are most notable for chicken carcasses from very small/small establishments. The smaller establishments may benefit the most from the protocols and requirements of the certifications.

Discussion

This report investigates whether GFSI-recognized certifications are associated with lower *Salmonella* and *Campylobacter* risks in raw poultry products. GFSI harmonizes certification programs, with the aim to enable food producers to be “once certified, accepted everywhere” (Global Food Safety Initiative, n.d.). The question of whether certified products are associated with lower pathogenic risk carries implications for both agribusinesses and policymakers, as the certifications are—in effect—signaling food safety in the marketplace. Our findings provide a foundation for evaluating the role and value of GFSI-recognized certifications in enhancing the safety of the food supply chain.

Our analysis reveals an association between certified products and a reduced likelihood of positive *Salmonella* tests for all three certification programs. Certified poultry products demonstrate a 4–6 percent lower probability of testing positive for *Salmonella*. These lower rates suggest notable relative risk reductions.

The results for *Campylobacter* tests, however, are less conclusive. Only FSSC-certified products show a statistically significant average marginal reduction in *Campylobacter* positive rates. Given the limited sample size of FSSC-certified products and the statistically insignificant results for BRCGS and SQF certifications, we refrain from making broad conclusions. Nevertheless, these findings suggest potential differences in the effectiveness of these certifications regarding *Campylobacter* control. The results also show that certified products are more likely to test negative for both *Salmonella* and *Campylobacter*. For safety-oriented buyers, sourcing from certified establishments may increase the likelihood of obtaining products that are negative for both *Salmonella* and *Campylobacter*. Further investigations are needed to ascertain the mechanisms behind these potential risk reductions.

The tests reveal important nuances between certifications and pathogens. In particular, the GFSI benchmarking process may not uniformly lower the risk of both pathogens across certifications. The differences in protocols of individual certifications may result in heterogeneous effects. Further, the reductions are heterogenous across different categories of poultry products, where the pathogen rates for many products are not statistically different between certified and uncertified products. These differences may not be immediately apparent to downstream food retailers and processors. The purpose of the GFSI benchmarking process is to harmonize different certification schemes, inevitably implying a certain degree of equivalency. The benchmark does not include pathogen target levels on products. To more effectively communicate pathogenic risk reduction, GFSI may formalize more stringent standards on positive rates of pathogen detection. This would ensure that the overall pathogenic risks are lower in certified products, while reducing uncertainty.

While the certified products are at least as safe as uncertified products, our analyses do not show pathogen reductions in all aspects. As only most but not all of the average marginal and joint effects we analyzed are statistically significant, the certifications are not always associated with pathogen risk reductions. Whether the degree of observed risk reduction meets expectations and cost-benefit considerations of agribusinesses, consumers, and policymakers may be a topic for further debate. Further, there remains an open question about the relative efficacy of third-party food safety certification versus retailer-mandated pathogen reduction targets, such as Walmart's program, which has been credited with broad industry impact (Beach, 2016; Walmart, n.d.). For instance, Walmart requires a *Salmonella* reduction target of 4-log reduction (a 99.99-percent decrease in Colony-Forming Unit[5]), in contrast to USDA, FSIS's sampling-based positive rate thresholds. These retailer-driven requirements may also influence overall pathogen risk across the supply chain.

The results highlight a need for continued government and private industry roles in monitoring and setting food safety performance standards. Major reductions in the pathogen rates were made prior to GFSI-recognized certifications became widespread (USDA, FSIS, 2021b; Ollinger & Bovay, 2020; Williams et al., 2021; Williams et al., 2020). While our data show that GFSI certification may be associated with equal or lower pathogen detection rates, the food safety risk is not entirely mitigated. The GFSI certifications may thus be seen as complementary to robust regulatory frameworks.

USDA, FSIS establishes science-based food safety standards that apply equally to all establishments. Furthermore, USDA, FSIS also provides independent oversight and regular inspections of establishments. This means that raw poultry establishments are under more frequent and consistent monitoring from USDA, FSIS, compared to the inspections and audits related to certifications. Increased monitoring may incentivize greater adherence to food safety standards, particularly among safety-oriented establishments aiming to demonstrate high food safety standards (Ollinger et al., 2024). Other regulatory efforts provide additional evidence for downstream food buyers to gauge food safety (Ollinger & Bovay, 2020). These efforts include ranking establishments into three categories[6] based on the maximum allowable percent positive of *Salmonella* tests and disclosing the results to the public. Such public tools can be used to complement the information conveyed by GFSI-recognized certifications.

This report raises topics for future research. While it identifies correlations between certifications and *Salmonella* and *Campylobacter* test outcomes, a causal relationship is not established. A panel dataset with information on when an establishment gets certified can be used for causal inference econometric analysis. Techniques such as difference-in-differences can be applied to compare before and after changes in pathogen detection rates to more precisely represent the effects of certification. Because establishments may differ in their underlying food safety practices, a more comprehensive

[5] A Colony-Forming Unit (CFU) is a measure used in microbiology to estimate the number of viable microorganisms in a sample. It represents a single cell or group of cells that can multiply and form a visible colony on a growth medium.

[6] See the USDA, FSIS website for details about categorization and disclosure.

dataset would help assess whether establishments that choose to become certified already have characteristics associated with safer outcomes. Additionally, the generalizability of our findings across different periods, products, and pathogens, remains unexplored.

It remains unclear whether certified products have a lower risk of contamination from other pathogens beyond *Salmonella* and *Campylobacter*, and whether our results apply to non-poultry meats and ready-to-eat products, especially against the backdrop that the effects are heterogenous across poultry products. Despite these open questions, our report finds that GFSI-recognized certifications show promise as a signal of food pathogen risk.

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Appendix A

Table A.1
Summary statistics by certifications and establishment size

Certification type	Size of establishment	Number of establishments	*Campylobacter* Samples	*Campylobacter* mean positive rate	*Campylobacter* SD	*Salmonella* Samples	*Salmonella* mean positive rate	*Salmonella* SD
Uncertified	Large	16	287	0.13	0.34	474	0.12	0.32
	Very small / small	271	1,731	0.22	0.41	3,127	0.14	0.34
BRCGS	Large	133	3,390	0.18	0.38	6,531	0.06	0.24
	Very small / small	57	664	0.19	0.40	1,262	0.07	0.26
SQF	Large	32	804	0.15	0.36	1,478	0.06	0.24
	Very small / small	77	620	0.12	0.33	929	0.12	0.33
FSSC	Large	0	0			0		
	Very small / small	4	23	0.04	0.21	36	0.08	0.28

SQF = Safe Quality Food; FSSC = Food Safety System Certification; BRCGS = Brand Reputation through Compliance Global Standard; SD = standard deviation.

Source: USDA, Economic Research Service calculations based on USDA, Food Safety and Inspection Service data and certifiers' directory.

Appendix B

Table B.1
Summary statistics by certifications and products

	Uncertified			BRCGS			SQF			FSSC		
	Samples	Mean	S.D.	Samples	Mean	S.D.	Samples	Mean	S.D.	Samples	Mean	S.D.
Salmonella												
Chicken carcasses	662	0.15	0.36	3,579	0.03	0.18	661	0.03	0.17			
Ground chicken	262	0.36	0.48	94	0.28	0.45	289	0.27	0.45	4	0.00	0.00
Chicken parts	2,495	0.11	0.31	3,754	0.07	0.26	1,163	0.08	0.27	32	0.09	0.30
Turkey carcasses	79	0.01	0.11	157	0.00	0.00	90	0.01	0.11			
Ground turkey	103	0.17	0.37	209	0.26	0.44	204	0.08	0.28			
Campylobacter												
Chicken carcasses	310	0.39	0.49	1,755	0.21	0.40	292	0.26	0.44			
Ground chicken	262	0.05	0.23	92	0.02	0.15	286	0.08	0.27	5	0.00	0.00
Chicken parts	1,266	0.22	0.41	1,840	0.20	0.40	555	0.18	0.38	18	0.06	0.24
Turkey carcasses	79	0.00	0.00	159	0.01	0.08	89	0.01	0.11			
Ground turkey	101	0.02	0.14	208	0.03	0.17	202	0.01	0.10			

S.D. = standard deviation. BRCGS = .Brand Reputation through Compliance Global Standard. FSSC = Food Safety System Certification. SQF = Safe Quality Food.

Note: Ground refers to ground and comminuted products.

Source: USDA, Economic Research Service calculations based on USDA, Food Safety and Inspection Service data and certifiers' directory.

Appendix C

Table C.1
Summary statistics by establishment size and products

Product types	Establishment size	*Salmonella* Samples	*Salmonella* Mean	*Salmonella* S.D.	*Campylobacter* Samples	*Campylobacter* Mean	*Campylobacter* S.D.
Chicken carcasses	Large	3,853	0.03	0.17	1,851	0.21	0.40
	Very small/ small	1,049	0.11	0.31	506	0.35	0.48
Ground chicken	Large	193	0.32	0.47	192	0.02	0.12
	Very small/ small	456	0.30	0.46	453	0.08	0.27
Chicken parts	Large	3,946	0.07	0.26	1,948	0.19	0.40
	Very small/ small	3,498	0.10	0.30	1,731	0.21	0.41
Turkey carcasses	Large	198	0.01	0.10	199	0.01	0.07
	Very small/ small	128	0.00	0.00	128	0.01	0.09
Ground turkey	Large	293	0.22	0.41	291	0.02	0.13
	Very small/ small	223	0.11	0.31	220	0.02	0.15

S.D. = standard deviation.

Note: Ground refers to ground and comminuted products.

Source: USDA, Economic Research Service calculations based on USDA, Food Safety and Inspection Service data and certifiers' directory.

Appendix D

Table D.1

Average marginal effect of control variables from the bivariate probit and probit models

	Bivariate probit: *Salmonella*		Probit: *Salmonella*		Bivariate probit: *Campylobacter*		Probit: *Campylobacter*	
	Estimates	[S.E.]	Estimates	[S.E.]	Estimates	[S.E.]	Estimates	[S.E.]
Large establishments	<0.001	[0.011]	-0.014*	[0.0082]	-0.039*	[0.022]	-0.04*	[0.021]
Turkey carcasses	-0.074***	[0.011]	-0.071***	[0.0092]	-0.19***	[0.0085]	-0.19***	[0.0085]
Chicken parts	0.032***	[0.0094]	0.032***	[0.0070]	-0.041***	[0.013]	-0.042***	[0.013]
Ground chicken	0.28***	[0.036]	0.27***	[0.034]	-0.16***	[0.020]	-0.16***	[0.020]
Ground turkey	0.16***	[0.045]	0.15***	[0.044]	-0.18***	[0.011]	-0.18***	[0.011]

SQF = Safe Quality Food; FSSC = Food Safety System Certification; BRCGS = Brand Reputation through Compliance Global Standard; S.E. = standard error.

Note: ***, **, and * represent significant levels of 1 percent, 5 percent, and 10 percent. Ground refers to ground and comminuted products.

Source: USDA, Economic Research Service calculations based on USDA, Food Safety and Inspection Service data and certifiers' directory.

Appendix E

Table E.1
Individual probit models of positive detection of *Salmonella* and *Campylobacter*

	Salmonella		*Campylobacter*	
	Estimates	**[S.E.]**	**Estimates**	**[S.E.]**
Certifier [Base: uncertified]				
SQF	-0.31***	[0.08]	-0.06	[0.12]
FSSC	-0.35	[0.33]	-0.92**	[0.40]
BRCGS	-0.26***	[0.07]	-0.08	[0.09]
Control variables				
Large establishment [Base: very small and small establishment]	-0.1*	[0.06]	-0.16*	[0.08]
Type [Base: chicken carcasses]				
Turkey carcasses	-0.88***	[0.25]	-1.83***	[0.25]
Chicken parts	0.23***	[0.05]	-0.17***	[0.05]
Ground chicken	1.08***	[0.10]	-0.95***	[0.24]
Ground turkey	0.71***	[0.16]	-1.39***	[0.20]
Constant	-1.38***	[0.08]	-0.53***	[0.07]
Sample size	13,837		7,519	
Akaike information criteria	7,487.65		6,678.79	
Bayesian information criteria	7,555.47		6,741.11	
Log-likelihood	-3,734.83		-3,330.39	

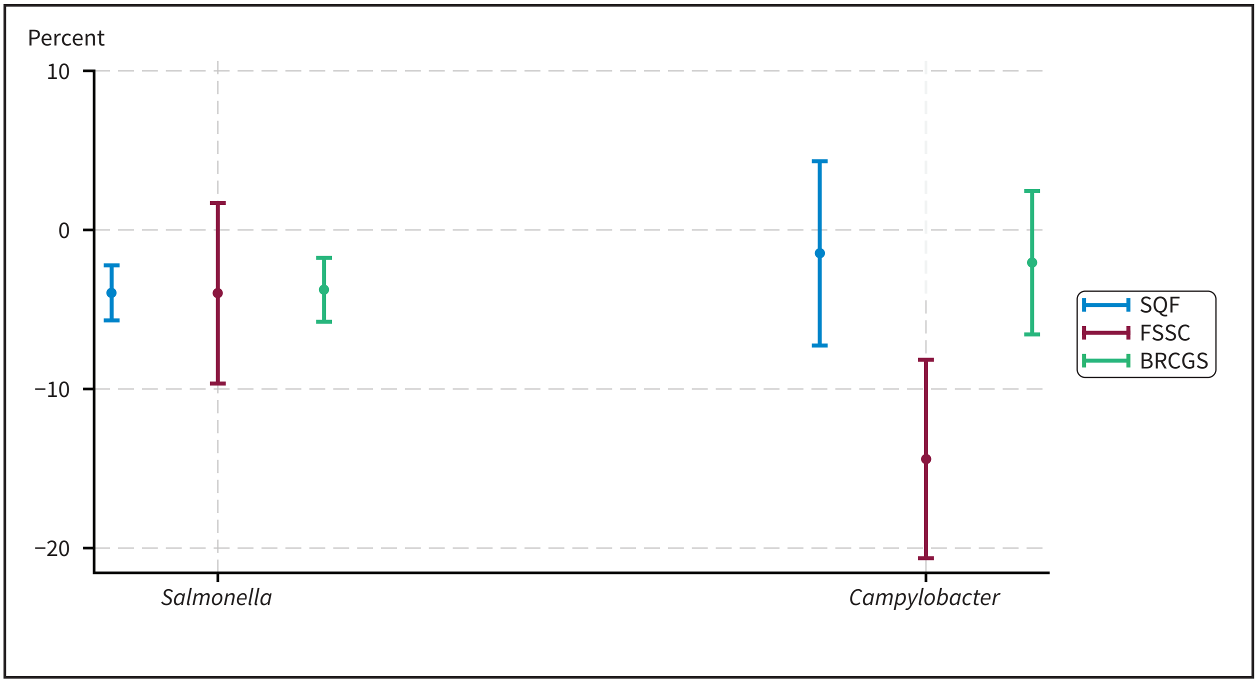
SQF = Safe Quality Food; FSSC = Food Safety System Certification; BRCGS = Brand Reputation through Compliance Global Standard; S.E. = standard error.

Note: ***, **, and * represent significant levels of 1 percent, 5 percent, and 10 percent. Ground refers to ground and comminuted products.

Source: USDA, Economic Research Service calculations based on USDA, Food Safety and Inspection Service data and certifiers' directory.

Appendix F

Figure F.1
Marginal effects of certifications on positive *Salmonella* and *Campylobacter* detection from individual probit models



SQF = Safe Quality Food; FSSC = Food Safety System Certification; BRCGS = Brand Reputation through Compliance Global Standard.

Note: Bars around marginal effect point estimates are 95-percent confidence intervals.

Source: USDA, Economic Research Service calculations based on USDA, Food Safety and Inspection Service data and certifiers' directory.

Appendix G

Table G.1
Bivariate probit models with interaction terms

	Salmonella		*Campylobacter*	
	Estimates	**[S.E.]**	**Estimates**	**[S.E.]**
Certified	-0.82***	[0.19]	-0.43**	[0.17]
Large establishments	-0.6***	[0.21]	-0.55**	[0.25]
Certified* large	0.39	[0.26]	0.35	[0.28]
Ground chicken	0.59***	[0.19]	-1.38***	[0.25]
Chicken parts	-0.42***	[0.13]	-0.57***	[0.13]
Turkey carcasses	-5.04***	[0.13]	-6.07***	[0.06]
Ground turkey	-0.13	[0.26]	-1.6***	[0.36]
Certified* ground chicken	0.37	[0.29]	0.7	[0.54]
Certified* chicken parts	0.71***	[0.20]	0.32*	[0.18]
Certified* turkey carcasses	0.82***	[0.20]	4.48***	[0.41]
Certified* ground turkey	0.55*	[0.32]	0.13	[0.44]
Large* ground chicken	0.24	[0.29]	-4.15***	[0.33]
Large* chicken parts	0.84***	[0.23]	0.43	[0.29]
Large* turkey carcasses	4.76***	[0.40]	0.55*	[0.30]
Large* ground turkey	0.75*	[0.42]	-3.92***	[0.42]
Certified* large* ground chicken	0.29	[0.38]	3.55***	[0.66]
Certified* large*chicken parts	-0.71**	[0.29]	-0.21	[0.32]
Certified* large* turkey carcasses	-1.13**	[0.55]	-0.65	[0.60]
Certified* large* ground turkey	0.01	[0.52]	4.16***	[0.58]
Constant	-0.9***	[0.13]	-0.19	[0.12]
ρ	0.22***	[0.03]		
Observations	7,516			
AIC	10,698.76			
BIC	10,961.9			
Log-likelihood	-5,311.38			

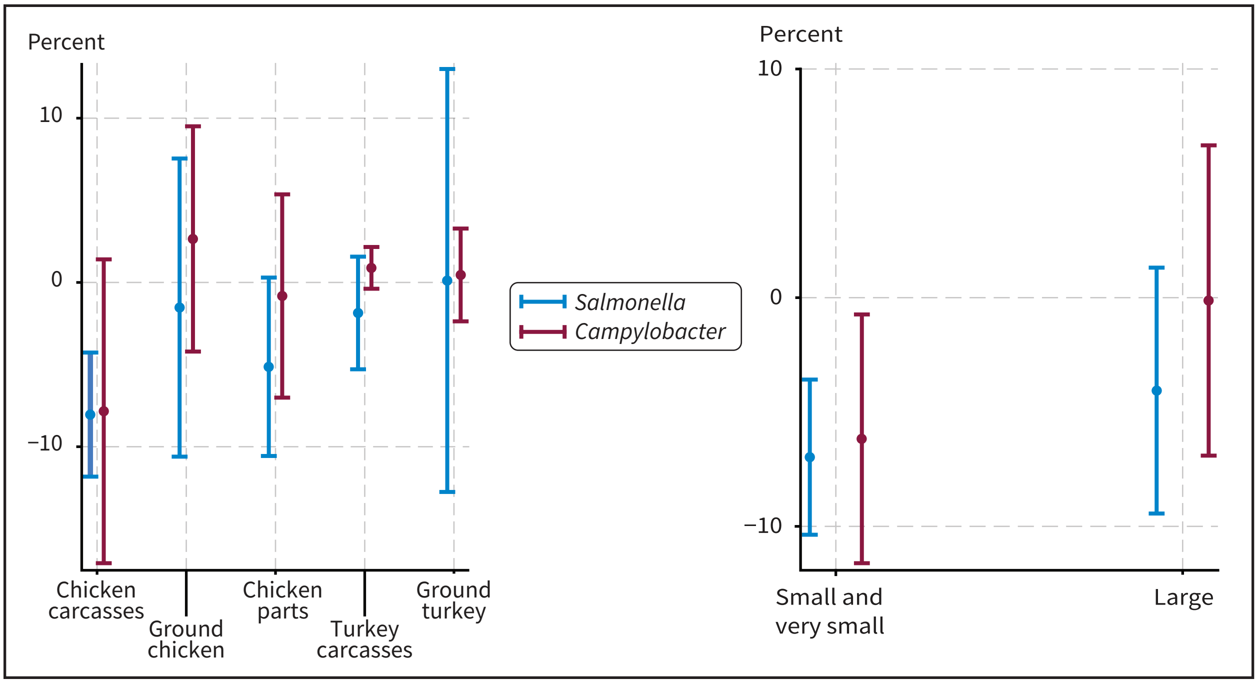
S.E. = standard error. AIC =. BIC = .

Note: Ground refers to ground and comminuted products. ***, **, and * represent significant levels of 1 percent, 5 percent, and 10 percent.

Source: USDA, Economic Research Service calculations based on USDA, Food Safety and Inspection Service data and certifiers' directory.

Appendix H

Figure H.1
Average marginal positive rates of *Campylobacter* of certified products (versus uncertified products) from the bivariate model with three-way interaction terms

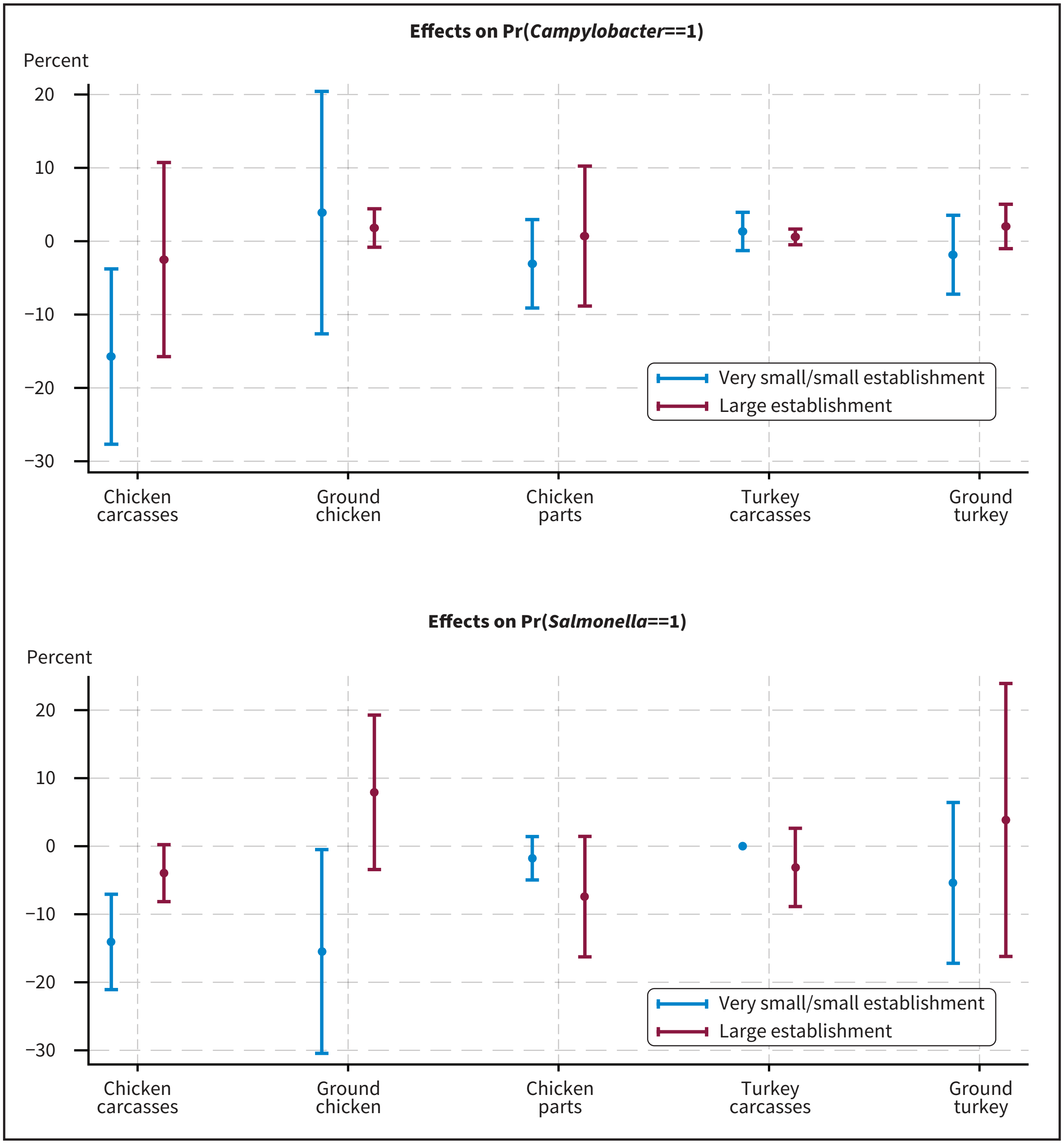


Note: Bars around marginal effect point estimates are 95-percent confidence intervals. Ground refers to ground and comminuted products.

Source: USDA, Economic Research Service calculations based on USDA, Food Safety and Inspection Service data and certifiers' directory.

Appendix I

Figure I.1
Average marginal positive rates of *Salmonella* and *Campylobacter* of certified products (versus uncertified products) from the bivariate model with three-way interaction terms



Note: Bars around marginal effect point estimates are 95-percent confidence intervals. Ground refers to ground and comminuted products.

Source: USDA, Economic Research Service calculations based on USDA, Food Safety and Inspection Service data and certifiers' directory.