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THREE ESSAYS ON FOOD SAFETY AND PRIVATE FOOD SAFETY CERTIFICATIONS

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THREE ESSAYS ON FOOD SAFETY AND PRIVATE FOOD SAFETY CERTIFICATIONS

DISSERTATION

A dissertation submitted in partial fulfillment of the
requirements for the degree of Doctor of Philosophy in the
College of Agriculture, Food and Environment
at the University of Kentucky

By

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ABSTRACT OF DISSERTATION

THREE ESSAYS ON FOOD SAFETY AND PRIVATE FOOD SAFETY CERTIFICATIONS

In the first essay, we provide a comprehensive literature review of the market of private food safety standards. Since the inception of private food safety standards in the late 1990s, producers, processors, retailers, and governments have been increasingly relying on them to provide assurances to food safety. This article first develops a conceptual framework for the market of private food safety standards through the lens of agri-food supply chain logistics, outlining how the key players in the market interact and classifying these interactions into fifteen categories. Second, we classify and review studies based on the interactions identified. Our review supports the identification of research gaps in this relatively new, though already important, area of research in contemporary agribusiness.

In the second essay, we aim to examine whether private food safety certification has a significant impact on food safety outcomes in the meat, poultry, and egg product industry. We merge manufacturer-level data from the governmental and private sectors and obtain a unique panel dataset that identifies manufacturer-level information such as private food safety certification status and food safety outcomes. We detect separation issues caused by rare event in our dataset, thus, we adopt the penalized maximum likelihood method. Using the pathogen results from the U.S. Department of Agriculture Food Safety

Inspection Service (FSIS) sampling programs as the measurement of food safety outcomes, we find that the British Retail Consortium (BRC) certification is negatively associated with *Salmonella* and *Campylobacter* test results; Safe Quality Food (SQF) is negatively correlated with *Campylobacter* and *Listeria* test results. We do not find significant results for the pathogens *E. coli* and non-O157 STECs.

The third essay examines relationship-specific learning-by-doing in the private food safety certification market. Relationship-specific learning refers to the efficiency gains caused by the human capital accumulation specific to the pair of a manufacturer and the certification body working together. Using data from the British Retail Consortium (BRC), we find that the time for obtaining a BRC certification reduces not only with the increase of manufacturers' overall experience certifying with BRC standard but also with the increase of joint experience between manufacturers and their certification bodies. The results indicate that relationship-specific learning exists in the process of getting BRC certifications, and it will potentially reduce the time and costs of obtaining BRC certifications and thus improve efficiency.

KEYWORDS: Food Safety Certification, Systematic Literature Review, Food Safety Outcomes, Relationship-Specific Learning, BRC, SQF

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CHAPTER 1. INTRODUCTION

Private food safety standards were developed in the late 1990s by the European retailers who wanted to harmonize food safety standards across the supply chain. Today private food safety certification schemes are adopted globally and have become integral to the global food system. At the same time, the scope that private food safety standards cover has been extended to environmental impact and health, safety, and welfare of workers and animals. Currently, there are seven internationally accepted private standards. These include GLOBALG.A.P., British Retail Consortium (BRC), Food Safety System Certification (FSSC) 22000, International Featured Standards (IFS), PrimusGFS, and Safe Quality Food (SQF). In the United States, there are 5,239 producers certified with GLOBALG.A.P., 2,448 manufacturers certified with BRC, 1,185 manufacturers certified with FSSC 22000, 11,713 producers or manufacturers certified with PrimusGFS, and 8,858 producers or manufacturers certified with SQF in 2018. Even with the proliferation of private food safety certification, the literature on the certification market, especially the U.S. certification market, remains a small strand in the agricultural economics literature.

The private food safety certification market is an essential part of the food supply chain in the United States. It involves various stakeholders, including private food safety standards, government, accreditation bodies, certification bodies, producers or manufacturers, consumers, and retailers. Consumers are essential part of the private food safety certification market. Consumers' awareness of private food safety certifications could reshape the private food safety certification market. Kanter et al. (2009) shows that the introduction of rBST-free and organic milk reduced consumers' willingness to purchase conventional milk. Additionally, researchers have conducted surveys and empirical studies that demonstrate that consumers are willing to pay a premium for organic food in Tabriz (Haghjou et al., 2013), Argentina (Rodrigues et al., 2007), Span (Urena et al., 2007), and Canada (Hamzaoui-Essoussi and Zahaf, 2012). Similarly, consumers may prefer products with private food safety certifications than those without. Therefore, consumers might push the labelling of private food safety certifications.

Investigating how stakeholders interact and affect each other has huge implications for these stakeholders and even society as a whole. Through this dissertation, I hope to provide some insights into the interactions between stakeholders in the market, especially the interactions between certification bodies and manufacturers. This dissertation provides a collection of three essays that explore the private food safety certification market. In the first essay, we develop a framework that defines potential interactions between stakeholders. We then conduct a systematic review based on this framework. We find that most of the studies focus almost exclusively on either the factors affecting the adoption of the private standards or the impact of the private standards. This review helps us identify research gaps in this relatively new, though already important, area of research in contemporary agribusiness.

Inspired by the research gaps discussed in the first essay, we analyze the relationships between private food safety certification and food safety outcomes. By employing the Penalized Maximum Likelihood method, we find the BRC certification is negatively associated with the U.S. Department of Agriculture Food Safety Inspection Service (FSIS) sampling results for *Salmonella* and *Campylobacter* tests; SQF is negatively correlated with *Campylobacter* and *Listeria* test results. However, we do not find significant results for the pathogens *E. coli* and non-O157 STECs.

The third essay explores the efficiency gains through learning specific to the pairs of manufacturers and certification bodies working together. Relationship-specific learning is explored in hospitals, the drilling industry, the movie industry, and the software firm, where individuals or firms provide services to multiple firms. It remains unknown whether relationship-specific learning exists in the context of the private food safety certification market. Using the British Retail Consortium (BRC) as an example, we find that the time to obtain a certification reduces as the pairs of manufacturers and certification bodies working together longer, which provides empirical evidence that relationship-specific exists between manufacturers and certification bodies as they develop human capital from working as pairs.

CHAPTER 2. THE MARKET FOR PRIVATE FOOD SAFETY CERTIFICATIONS: CONCEPTUAL FRAMEWORK, REVIEW, AND FUTURE RESEARCH DIRECTIONS

2.1 Introduction

Food supply chains have become increasingly complex and of a global nature. For example, it is not uncommon to find raw food products such as mixed berries or mixed nuts sold in a single package to an end-user consumer, consisting of food from multiple countries. As another example, a consumer's preferred grocery retailer may source seasonal fresh produce items from multiple producers and/or parts of the world in order to make a product available year-round. Advances in supply chains for raw food products have tremendously improved supply reliability in some regards, but these advances can make it more difficult to monitor whether producers or actors in a complicated global production supply chain are maintaining best practices for food safety. The inability to ensure food safety presents a risk, and therefore, a cost to society. Each year worldwide, the consumption of unsafe food causes 600 million cases of foodborne diseases (World Health Organization, 2015). In the United States, CDC estimates that 48 million people get sick, 128,000 are hospitalized, and 3,000 die from foodborne diseases each year (Painter et al., 2013; Scallan et al., 2011a; Scallan et al., 2011b). Given (i) the reliability benefits of contemporary raw food product supply chains and (ii) the adverse health events and associated societal costs from consuming unsafe food, there is a high value in understanding how to improve food safety monitoring in the global food supply chain. Private food safety certifications are a market innovation that can support the development and maintenance of a safe global food supply chain. Their relative novel prominence since their initiation in the 1990s means we are still learning about the organization of the overall system of private food safety certifications, and both its effectiveness and robustness in terms of achieving food safety goals.

Indeed, while the market for private food safety certification has become integral to the global food system, relatively little of its function in the market- and supply chain coordination is known. The literature on private food safety certification has been rapidly expanding, but it remains a small strand in the agricultural economics literature. For example, we are aware of only one review conducted on a topic similar to the one here, but with a narrower focus (exclusively on three European private standards including GLOBALG.A.P., BRC, FSSC 22000, and IFS) (Rao et al., 2021). By comparison, our study proposes a conceptual framework for this new market and synthesizes existing research findings on all seven global, private food safety standards. Specifically, our study seeks to answer the following questions:

1) What stakeholders and interactions conceptually define the system of private food safety certifications?

2) What evidence exists on how this private certification system affects its stakeholders?

3) Which interactions in this private certification system have been studied in the literature, and what is learned from these studies?

4) Which interactions from this private certification system deserve priority in new research efforts?

In response to the first question, we devise a conceptual framework that describes the seven key stakeholders and identifies 15 actions that define the private food safety certification system. For the second question, we conduct a literature search of studies on global private food safety standards and find 32 relevant peer-reviewed articles. In our response to the third and fourth questions posed, we review the studies found in the literature search. We find a strong emphasis on two categories of actions defined in our conceptual model--the producer decision to adopt private food safety certifications and the production-side impacts of private food safety certifications. For the former, we find studies examining the relationship between producer adoption choice and various factors. Collectively, these studies illustrate the context-specific nature of the adoption decision and documents important sources of heterogeneity due to farm-level, household-level, and market-level characteristics among other factors. Regarding the production-side impacts of private certifications, we find studies examining the impacts on farm-level, firm-level, and industry-level outcomes; overall, these studies indicate positive production-side impacts of private certifications. Considered as a whole, the literature review we present shows significant gaps in our collective knowledge about the system of private food safety certifications. Areas of research we identify as high priorities include the producer's choice between competing certification bodies, understanding the certification body market (e.g., the competition between certification bodies to have producers adopt their body's standards), consumer preferences for food safety certification, and the broader impacts of food safety certifications (e.g., frequency, severity, and impacts of food safety recalls), and finally, evidence on whether the proliferation of private certifications improves the safety of our food supply system.

The article is structured as follows. We first discuss the historical and institutional contexts for the topic. We then present a framework that describes the key stakeholders in the private food safety system and summarizes how they interact. We group and synthesize studies based on the various interactions outlined in the conceptual framework. We end by articulating a set of questions that the literature has yet to address.

2.2 Historical and Institutional Contexts for Understanding Private Certifications

The genesis of food safety practices and standards began with retailers who formalized food safety standards and imposed expectations of meeting them on their suppliers. In this sense, food safety standards are business-to-business standards that allow suppliers to strategically differentiate themselves amongst competitors as opposed to signaling devices to consumers via product labels that food is safe (Herzfeld et al., 2011). The first widely adopted private food safety standards were initiated by retailers in European countries in the late 1990s and early 2000s, though even in the United States food safety practices and standards were being imposed on suppliers by retailers as early as 1982 following an *E. coli* O157:H7 outbreak attributed to McDonald's hamburgers. A second E.coli outbreak in 1993 attributed to hamburgers from the fast-food chain Jack-in-the-Box is understood by various food safety stakeholders as a significant event in the U.S. food system that pushed individual CEOs to privately invest in food safety independent from government regulation (Andrews, 2013). While individual-level experiences with foodborne illness have impacted private investments in food safety, other factors including the globalization of the agri-food system, growing power of retailing industry, consumers' demand for safe and quality foods, and the limited effectiveness of public institutions in ensuring the safety of food products have also contributed to the rise of food safety standards in the private sector (Fulponi, 2006; Hatanaka et al., 2005; Henson and Reardon, 2005; Lin, 2014).

Over the past two decades, there has been a proliferation of private food safety standards (also known as private food safety management systems to the industry) and private entities that certify producers, processors, and manufacturers as having met these standards. These self-imposed standards are determined by commercial or non-commercial private entities, including firms, industry organizations, and non-governmental organizations (NGOs) (Herzfeld et al., 2011). They can be further classified as either (i) individual company standards set by an individual firm and are unique to the firm, or (ii) collective standards that can apply at the national, multi-national, or global levels. An example of an individual company standard is Tesco Nature's Choice since it is set by Tesco, the United Kingdom's largest multi-national supermarket chain. Tesco Nature's Choice, a fresh produce standard, specifies agricultural practices that growers much achieve to be a Tesco produce supplier. An example of a collective standard with origins at the national level is the British Retail Consortium (BRC) global standard program. Unlike Tesco Nature's Choice, the BRC standard, which specifies best practices for manufacturers and processors, was not unique to one retailer. As recognition of the BRC standard increased, it became a collective national standard that is accepted worldwide. An example of a collective standard with global origins is the International Organization for Standardization (ISO), a non-governmental organization consisting of standards organizations from 165 countries. ISO developed the global standard named ISO 22000, which specifies best practices for manufacturers, processors, and farmers. Similar to the BRC standard, ISO 22000 is not unique to one retailer and so may be adopted by any retailer whose supply chain entities adhere to specified standards.

The private food safety certification system was developed to serve various roles; three likely functions are (1) risk reductions across multiple entities in food supply chains, (2) product differentiation among input providers along reliability and quality dimensions, and (3) consumer confidence in and demand for end products. In serving these roles, the current system of private food safety certification resembles the proliferation of disparate standards and certifiers in the United States and internationally surrounding organic products in the late 1980s and 1990s and is distinct from U.S. organic standards and certification since the year 2000 when a uniform federal standard was implemented through the National Organic Act. The U.S. Food Safety Modernization Act (FSMA) may be an early prototype for a similar federal standard in the United States with respect to food safety. However, the development of a federal food safety standard may face more significant obstacles since it may give rise to an implicitly "unsafe" food market with low or even non-existent demand.

The "market" for private food safety certification works alongside the public regulatory environment. For example, in the United States, the Food and Drug Administration (FDA) and the U.S. Department of Agriculture (USDA) have primary roles in the public system. Together, both agencies have established preventive control type regulations based on the Hazard Analysis and Critical Control Point (HACCP, see appendix A for a full abbreviation list) concept. In addition, these agencies oversee inspections of regulated food-producing and processing facilities to determine compliance with laws and regulations. In the U.S. public system, food safety regulation has been limited to products such as meat, poultry, juice, and seafood, which historically have carried relatively higher food safety risks than other food products. In contrast, private food safety standards, many of which are also based on the HACCP concept, are business-to-business standards and cover a wider range of food product categories. They have been used by retailers to identify suppliers, in addition to shifting the food safety responsibility from retailers to producers.

The relationship between public and private governance systems and comparisons of their relative efficacy is complex and controversial. Private standards do not simply serve as a complement to public standards—the regulatory spheres of public and private mechanisms overlap (Lin, 2014). For example, all meat in the United States is inspected and tested for contamination on a regular basis by the Food Safety and Inspection Service (FSIS), a sub-agency within the United States Department of Agriculture, yet approximately ten percent of U.S. meat processors also privately certify their meat products to achieve a global, collective-type standard[1]. In terms of redundancies, within these meat processors' private certification process there may be additional inspection and tests for contamination above and beyond FSIS. Similarly, there are private individual standards that overlap with public standards. Costco Wholesale requires their meat supply is subject to more intensive testing than that implemented by FSIS maintains. The reason for this type of overlap is that some retailers seek out a higher standard than that required by the public standard. Testing for what drives this type of behavior is outside the scope of our study, though for publicly held private companies, the decision to use private standards that are higher than public ones should be in the interest of their public stakeholders. One way to interpret this is that private standards are adopted due to a private motive of profit maximization. Indeed there is some evidence that private standards offer retailers more

[1] This is based on our own data tracking U.S. meat processors certification status to BRC, FSSC 22000, PrimusGFS, and SQF for the years of 2015-2018.

flexibility and adaptability, which can be useful for meeting retailers' private motives, and even result in a more effective provision of food safety relative to public standards (Lin, 2014).

On the other hand, private standards are not without potential disadvantages to the public precisely because private standards are developed to serve the needs of private retailers with a profit maximization motive, rather than a social objective to generate public goods. If private and social objectives are not aligned with regards to the provision of food safety, then the legitimacy of private standards to provide safe food is eroded (Halabi and Lin, 2017). For an example of how legitimacy might be affected by misaligned objectives, certifiers may have an incentive to compromise the integrity of inspections to seek future cooperation (Rao et al., 2021). Ultimately, it is not clear that private standards will lead to greater provision of food safety than public standards, which is another potential reason for some degree of overlap between private and public standards. Consequently, there is value in studying how private food safety standards and certifications are implemented to help assess when private standards are likely to under-provide food safety relative to a public standard. To this end, we systematically consider the supply chain logistics of how private standards and certifications work in practice for stakeholders, especially interactions between stakeholders.

In this study, we focus on seven internationally accepted collective standards. These include one pre-farm gate standard (GLOBALG.A.P., formerly known as EUREPGAP), three manufacturing and processing standards (British Retail Consortium [BRC], Food Safety System Certification [FSSC 22000], and International Featured Standards [IFS]), and three standards that cover both pre-farmgate and processing/manufacturing (ISO

22000, PrimusGFS, and Safe Quality Food [SQF]). The Global Food Safety Initiative, which provides a forum for benchmarking food safety standards against a common set of criteria, recognizes all but the ISO 22000 standard (the ISO standard was previously recognized) [2]. Note that these standards affect not only the quality of final products but also the whole organization of the supply chain. For example, GLOBALG.A.P. is a standard that covers not only aspects of food safety but also environmental protection, traceability, and the safety and economic welfare of workers.

2.3 Food Safety Certification Market: An Overview and Conceptual Framework

2.3.1 Certification Adoption by Location, Operation Type, and Product Category

Table 2.1 presents the number of certified sites of the aforementioned seven private standards in the U.S. and world, covering the years 2015 and 2018 for the United States and 2018 for the world. As the table shows, four standards use a tiered grading system while the remaining three simply use a "pass or fail" grading system. The two U.S.- based standards, PrimusGFS and SQF, are the most commonly adopted in the United States, while the remaining Europe-based standards dominate the international markets.

Table 2.2 presents the number of certified sites in the U.S., by operation and product type, for PrimusGFS and BRC, the two standards for which we have data. The top panel (2a) describes the sites adopting PrimusGFS, the most popular standard in the United States. In 2018, 59.7% of the 11,713 certified sites were farms. Alternatively, if we break down sites by operation type—whether they fall under Good Agricultural Practices (GAP)

[2] The Global Food Safety Initiative recognition means meeting benchmarking requirements. It offers a passport to the global market for the standard holders and the companies that they certify. The Global Food Safety Initiative recognized ISO 22000 until around 2018.

or Good Manufacturing Practices (GMP), then 80.2% of the sites certified by PrimusGFS were for GAP. The lower panel of table 2.2 (2b) shows the U.S. sites certified using BRC standards, broken down by the eighteen product categories. In 2018, the primary food categories were dried foods and ingredients (26.4% of the 2,448 certified sites), raw prepared meat and vegetables (17.2%), and bakery (16.1%).

2.3.2 A Conceptual Framework of the Market for Private Food Safety Certification

The private food safety system comprises multiple, distinct sets of food safety standards (owned by respective standard holders), numerous entities that certify producers, processors, and manufacturers as having met these standards, and several accreditation bodies that serve to certify the certifying entities. Accreditation bodies oversee the quality conformity assessment for various standards. Each country generally has one or two accreditation bodies, either non-profit organizations (e.g., the ANSI-ASQ National Accreditation Board [ANAB] in the United States) or government entities (e.g., the China National Accreditation Service in China). Certification bodies are independent companies that carry out the actual certification. For example, as of 2020, 26 certification bodies in the United States could certify firms as having met the BRC food standard.

We suggest a conceptual framework of characterizing and relating private food safety certification, listing the abovementioned seven types of players, and delineating the potential ways they can interact (see Figure 2.1). The numbered arrows in the figure denote actions and their directionality. Actions are as follows:

Action 1. Retailers initiated and shaped private food safety standards. Historically, private food safety standards have arisen from retailers. For example, GLOBALG.A.P.

started as an initiative by retailers belonging to the Euro-Retailer Produce Working Group in 1997, and the BRC standard was founded in 1996 by retailers.

Action 2. Retailers may require suppliers to receive a food safety certification. Many retailers now require suppliers to obtain a certification with one recognized standard. Wal-Mart was the first U.S. grocery chain to impose this requirement in 2008, followed by others such as Target. Retailers vary on the requirement of which standard to certify. While many European stores require fresh produce producers certified to GLOBALG.A.P. (e.g., Tesco, Royal Ahold), Wal-Mart requires that food suppliers certify to any private food safety standard recognized by the Global Food Safety Initiative.

Action 3. Governments can recognize accreditation bodies. Governments can also play a role in these markets. For example, under the new Accredited Third-Party Certification Program established under the FSMA, the FDA can recognize accreditation bodies by reviewing their applications. Upon recognition, these accreditation bodies are included in a public registry. These government accreditations matter: a foreign producer's imports in the United States can undergo expedited review if the producer is certified by a certification body accredited by an FDA-recognized accreditation body. The first recognized accreditation body in this program is ANAB, followed by International Accreditation Services (IAF).

Action 4. and Action 5. Accreditation bodies accredit certification bodies after successful conformity assessment on the certification bodies against safety standards. In reality, there is little demand for unaccredited certification bodies.

Action 6. All certificates must be issued by auditors from certification bodies that are approved by the respective standard. Standard holders impose competency requirements (e.g., education and experience of auditors) for approving certification bodies.

Action 7. Certification bodies can seek multiple accreditations. Many certification bodies (especially leading international ones such as Bureau Veritas, SGS, and SAI Global) have accreditations from multiple countries.

Action 8. Certification bodies can seek to offer one or multiple standards. Some certification bodies specialize in only one standard while others can offer multiple. Certification bodies also tend to specialize by scope (e.g., farming vs. manufacturing) or product category. For example, the American Institute of Baking, now known as AIB International, tends to specialize in bakery certification.

Action 9. Producers seek certification for adoption by picking (typically) one single standard. Each standard holder generally lists the approved certification bodies on their websites (some standards [such as BRC] even post ratings of their certification bodies).

Action 10. Producers choose a certification body. Certification bodies charge different application/administration fees for different standards.

Action 11. Certification bodies certify producers. Producers are responsible for the costs of (1) auditors' travel, (2) certification, and (3) fixing any nonconformities identified by the certifier(s).

Action 12. Standards impact producers through certification. The primary benefits of certification include achieving premium supplier status, enhanced market access, and additional export channels. Generally, producers do not signal food safety certification to consumers with labels on the product package.

Action 13. Standards may impact retailers. Certification reduces retailers' uncertainty of product quality and may reduce the need of retailers to integrate backwards to acquire suppliers.

Action 14. Consumers may prefer products with a certification or prefer one standard over another. At the same time, explicitly signaling safety certification for some products (but not others) could potentially stigmatize those without such labels, prompting consumers to think they might be unsafe. A study shows that the introduction of rBST-free and organic milk reduced consumers' willingness to purchase conventional milk (Kanter et al., 2009).

Action 15. Finally, consumers may place more trust in retailers that require suppliers to undergo food safety certification and communicate to consumers their supply chain stewardship efforts to reduce food safety risks. However, such information is generally not communicated by retailers to consumers at this time.

The conceptual framework presented here illustrates the complexity of the private food safety certification market and how the various players in the market can interact. In the following section, we summarize our findings in terms of the academic literature on this market.

2.4 Literature on Private Food Safety Certification

2.4.1 Search Strategy

We chose two databases (CAB Abstracts [CABI] and Global Health) within which to focus our initial search based on their comprehensive coverage in the areas of agriculture, applied economics, and health. We conducted a systematic review of the literature in the two databases for articles containing any of the following keywords in topics (which covers more articles than by searching in titles): private food safety standards, third-party certification, voluntary certification, FSSC, BRC, SQF, ISO 22000, IFS, GLOBALGAP (and its variation Global G.A.P.), EUREPGAP (former name of GLOBALGAP) —and the full names of the abbreviations. We initiated our review starting in July 2018 and concluded in April 2019. We did not impose any restriction on the publication dates and identified 1,967 articles with potentially relevant titles and abstracts. We further screened the titles and abstracts using three predefined inclusion criteria: in English, in peer-reviewed journals, and relevant to one of the areas described in the previous section (the studies we wanted to include were research-based relationships related to food safety certification within this market). For example, we included articles that studied the impact of certification on one of the market players. In addition, we went through the reference lists of the retrieved articles and added seven articles that met the eligibility criteria. Figure 2.2 describes the search process and the number of articles excluded in each step. Applying the inclusion criteria narrowed the scope of the review to 32 articles. We want to acknowledge that our review is narrowly focused on a particular type of certification, although our topic relates to a broader literature on standards and certification, which is beyond the scope of the survey.

2.4.2 Data Summary

We begin by summarizing basic information about the included articles. Table 2.3 presents the author(s) (in alphabetical order), publication year, country/countries of study, data period, data type (survey or secondary data), standard(s), product(s), sample size, and methodology for all articles. These are indicators that help us understand the distribution of research topics. From 2009 to 2019, there were about two to five articles on this topic each year.

Out of the 31 articles, seven are cross-country studies (Andersson, 2019; Drescher et al., 2009; Ehrich and Mangelsdorf, 2018; Fiankor et al., 2019; Henson and Humphrey, 2009; Henson et al., 2011; Minor et al., 2019) with one focusing on African countries (Henson et al., 2011) and two focusing on European countries (Andersson, 2019; Fiankor et al., 2019); the other 24 are regional studies within a country. Taking a closer look at the 24 articles, study settings are countries in Africa including Kenya (Asfaw et al., 2009a, 2009b, 2010; Ehlert et al., 2014; Kariuki, 2014; Kariuki et al., 2012; Muriithi et al., 2011), Ghana (Annor et al., 2016; Kleemann et al., 2014), Senegal (Colen et al., 2012), and Madagascar (Subervie and Vagneron, 2013); Asian countries including Thailand (Holzapfel and Wollni, 2014; Kersting and Wollni, 2012; Lippe and Grote, 2017), and Vietnam (Hansen and Trifković, 2014); European countries including Germany (Gawron and Theuvsen, 2009), France (Latouche and Chevassus-Lozza, 2015), Portugal (Lippe and Grote, 2017), and Romania (Păunescu et al., 2018); the United States (Bar and Zheng, 2019; Seok et al., 2016); and South America including Chile (Handschuch et al., 2013) and Peru (Lemeilleur, 2013; Schuster and Maertens, 2013, 2015). The geographic focus on African countries and other developing regions suggests that private food safety standards may be particularly important in places where public food safety standards are inadequate or weakly enforced.

Fresh fruits and vegetables are the subjects of the majority of the articles, likely because bacterial contamination poses a more significant health threat for foods consumed raw. Ten studies examine the broad category of fresh produce (fruit and vegetables), while others focus on one or two particular types of fruit or vegetables (e.g., asparagus and pineapples), with one exception focusing on pangasius catfish. In terms of data sources, researchers mainly rely on author-conducted surveys (primary data) as opposed to secondary data. Studies using primary data are generally cross-sectional with relatively small sample sizes. The average number of observations for these studies is 288, with the range being 43 to 556. Only one of these survey-based studies did a follow-up survey the next year (Holzapfel and Wollni, 2014). Nine studies use secondary data; these typically combine data from private food safety certification online databases with national-level data (Andersson, 2019; Bar and Zheng, 2019; Drescher et al., 2009; Ehrich and Mangelsdorf, 2018; Fiankor et al., 2019; Henson and Humphrey, 2009; Latouche and Chevassus-Lozza, 2015; Mohammed and Zheng, 2017; Seok et al., 2016).

As pioneers and the most popular certifications, BRC and GLOBALG.A.P. are almost ubiquitous in this literature. Other certifications such as IFS (Ehrich and Mangelsdorf, 2018; Gawron and Theuvsen, 2009; Latouche and Chevassus-Lozza, 2015), SQF (Hansen and Trifković, 2014; Mohammed and Zheng, 2017; Schuster and Maertens, 2015; Seok et al., 2016), ISO 22000 (Mohammed and Zheng, 2017; Păunescu et al., 2018), and FSSC 22000 (Mohammed and Zheng, 2017) appear less frequently, even though certified sites to these standards are available online (except for IFS).

We categorize all eligible articles using the actions depicted in Figure 2.1. Of the fifteen actions we describe in the conceptual framework, we only find substantial literature on two actions. Surprisingly, almost all (31) of the studies focus on either how producers seek certification to adopt a standard (Action 9) or the impact of certification on producers (Action 12). Only one article investigates how producers and certification bodies interact

(Actions 10) (Bar and Zheng, 2019). The absence of studies for the majority of identified actions is striking and suggests areas for future research.

In total, 18 studies investigate the factors affecting the adoption of standards, and 21 estimate the impacts of certification. The main finding of these studies along with the author(s) (in alphabetical order) and are presented in tables 2.4 and table 2.5, respectively. Several studies touch on both topics (Asfaw et al., 2009a, 2009b; Handschuch et al., 2013; Henson et al., 2011; Holzapfel and Wollni, 2014; Kleemann et al., 2014; Păunescu et al., 2018; Subervie and Vagneron, 2013) and they are reported in both tables.

2.4.3 Literature on Producer Adoption of Standards (Figure 2.1, Action 9)

We categorize the factors affecting the adoption of private food safety certification into four categories: farm characteristics, (producer) household characteristics, access (to information, markets, and financial resources), and 'other.' Household characteristics, especially the age and education level of the head of household, are the most investigated factors. In general, a younger or more educated head of household has a higher probability of undergoing private food safety certification; one potential explanation is that they are more willing to try new technologies. The education levels of other (adult) family members play a similar role (Asfaw et al., 2009b, 2010; Lippe and Grote, 2017). One study finds education is negatively correlated with adoption and attributes this to the interaction of education and off-farm income (Kariuki, 2014). Producers with more education have more off-farm employment opportunities, and this may distract farmers from fully committing to their farming activities and undergoing any process for certification (Kariuki, 2014; Kersting and Wollni, 2012; Muriithi et al., 2011). On the other hand, there is evidence that additional income from off-farm activities can be used to invest in farm assets or facilities for standard compliance, thus increasing the probability of adoption (Annor et al., 2016; Asfaw et al., 2010).

Other household factors that correlate with adoption include household wealth, experience with contract farming, a high-value product or supply chain, or compliance with public standards, and awareness of expectations for environmental and social stewardship. The evidence on household size is mixed, while gender is found to matter (a male head of household is more likely to adopt). One study measures the correlation between the producer’s openness to risk and the adoption of certifications. The results indicate that farmers with GlobalG.A.P. certifications are associated with higher levels of risk aversion than farmers with organic certifications (Kleemann et al., 2014).

As for farm characteristics, farm size and assets are found to be positively related with adoption, lending support to the concern that small-scale producers might be excluded from European and North American export markets because they lack the resources to comply with the requisite standards. In addition, the presence of an irrigation system, from a simple water pump to a sprinkler or drip-irrigation system, is positively correlated with adoption.

For access-related farm characteristics—which represent farmers’ access to information (e.g., ownership of mobile phones and television sets), market, communication, and financial support—the evidence is largely positive. For example, external supports in the forms of extension services, support from buyers or donors (such as for technology, financing, and management), access to credit and training, help producers transition to a certification scheme. One caveat is that training and certification protocols could add to the workloads of producers and distract them from farming (Lippe and Grote, 2017). Other characteristics such as the number of exchanges seasons with buyers in a year, product price, and a change in the purchasing entity are also found to be significant factors in adoption[3].

Only one article investigates firm-specific factors influencing the adoption decision (Henson et al., 2011). Firm capacity, buyer's demand for private food safety certification, size of horticulture sector in the country, and technical and financial support are found the key factors that affect a firm's decisions to undergo certification.

Farm-level and firm-level studies look into micro factors that affect the adoption of certification, while country-level studies investigate macro ones. Three articles use aggregate national-level data to examine the adoption of standards at the country level (Drescher et al., 2009; Herzfeld et al., 2011; Mohammed and Zheng, 2017). Generally, larger and wealthier countries with better infrastructure (measured by factors such as road conditions, being the home country of a private standard, and the number of certification bodies), higher institutional quality, and greater economic development have more certified firms.

2.4.4 Literature on the Production-side Impacts of Certification (Figure 2.1, Action 12)

Table 2.5 summarizes the 20 articles that investigate the impacts of certification, broken down into farm-, firm-, and industry-level. At farm level, private food safety certification is found to increase farmers' financial performance (as measured by the rate of return, revenue, consumption expenditure, and net income) and market performance (as measured by prices received and quantities sold by producers).

3 Low number of exchange seasons indicate possibilities of frequent change of buyers, and high number of exchange seasons suggests stability in the market access (Kariuki, 2014).

At firm level, researchers find that private food safety certification may improve firm management and productivity (Gawron and Theuvsen, 2009; Latouche and Chevassus-Lozza, 2015; Păunescu et al., 2018). Likewise, firms with certifications provide higher wages, longer periods of employment, and more training, and have employees showing better physical and mental health (Colen et al., 2012; Ehlert et al., 2014). At industry level, certification leads to vertical integration, especially among small-scale producers (Schuster and Maertens, 2013).

A few studies focused exclusively on the impact of certification on exports; the results are summarized at the bottom of table 2.5. Most studies find that certification has a positive impact on export value or export volume, while one finds that certification has no significant impact either export value or export volume (Schuster and Maertens, 2015). Two articles investigate the heterogeneous impacts of certification on exports: One finds that private food safety certification has a positive impact on firms only in mid-and high-income countries (Ehrich and Mangelsdorf, 2018), while another finds that it has a positive impact on farms in low- and mid-income countries (Fiankor et al., 2019). Overall, the empirical evidence seems to point to a positive impact of certification on producers.

2.5 Research Gaps

The literature review shows that studies on food safety certification have focused almost exclusively on interactions between producers and standards. Within this area, the research has been mainly on the GLOBALG.A.P. standard, with most authors using survey data collected from producers. Given GLOBALG.A.P. is the most popular standard worldwide (Table 2.1), this seems a reasonable observation. However, studies on other standards are warranted, particularly ones utilizing firm-level panel data. For example, standard holders likely compete for farmers and manufacturers; yet the literature provides scant insight into how a producer chooses one standard over others. The interactions between other players have been ignored as well. Among these, we rank that the following interactions to have a high priority for new research:

2.5.1 Producer's Choice of Certification Body and Vice Versa (Figure 2.1, Actions 10, 11)

Only one article investigates how producers and certification bodies interact (Bar and Zheng, 2019). Using a conditional logit choice model, the study combines certified sites data from BRC's online database with certification body data retrieved from the listed producers' websites to examine producers' choices of certification bodies in the United States. Based on 2011-2015 panel data, the results show that firms are more likely to choose a certification body perceived as more lenient in grading, closer in distance, and the one they chose from last year.

Though the study touches on several important factors in choosing certification bodies, it focuses on one manufacturing standard and does not address other key factors, especially prices. In particular, the sensitivity of producers to certification costs and cost savings from multi-site certification for the same company remain unaddressed, largely because certification costs depend on each firm's size and preexisting food safety practices, making cost/price data hard to obtain. Vice versa, little is known on questions such as whether there are efficiency gains (learning by doing) for a certification body from working with the same site for a long time.

2.5.2 The Certification Body Market (Figure 2.1, Actions 4-8, 11)

Currently, the market for food safety certification receives little economic analysis, such as the competition and oversight of certification bodies. Possible research questions could include: why do many certification bodies obtain multiple accreditations from various countries (Figure 2.1, *Action* 7), how do certification bodies decide what standard(s) to offer in a specific county (Figure 2.1, *Action* 8), will certifying to only one standard be more profitable than to multiple standards—known as single-home vs. multi-home decision in the industrial organization literature (Figure 2.1, *Action* 8), will offering consulting or training attract more business (Figure 2.1, Action 11), should the fact that producers pay certification bodies—possibly making them less independent—be cause for concern (Figure 2.1, *Action* 11), and what kind of role should governments play in the certification body market (currently it is unregulated)?

2.5.3 Consumer Preferences for Safety Certification (Figure 2.1, Action 14)

Though food safety certification is used primarily in the business-to-business realm, we occasionally observe products on the market labeled as having been certified. Indeed, after consulting each of the standards' websites, we found no language prohibiting the labeling of certification on a product. Figure 2.3 shows a photo of a product found at an international market in Lexington, Kentucky in 2018. The Chinese condiment producer placed a label indicating ISO 22000 certification on a prominent location of the package. We observe such practice for a few products coming from Taiwan, too, but not yet for products originating from the United States.

This raises more interesting research questions: Why is food safety certification generally not signaled to the consumer through labels? Will such labeling overwhelm or confuse consumers (who may only be aware of public certification systems), stigmatize competitor food products without safety certification labels, or bring value to producers? By compelling supplier compliance to certain food safety certifications, retailers exert their influence on food safety without taking on additional legal and economic liability. The onus of proof of safety is shifted upstream in many cases to the suppliers or at least there is an effort to isolate liability. Under what conditions will retailers welcome a new safety certification labeling? Could such preferences vary by retailer size or by product type? The literature is rich in studies on consumer preferences for country-of-origin labeling, organic attributes, etc., but has not yet examined consumer preferences for private food safety certification. Understanding the value of the signaling certification to consumers may provide insight to producers weighing the benefits against the costs of certification labeling. The physical cost of labeling safety certification is likely to be low; however, producers and retailers could also be concerned about the legal liability of labeling food as safe or litigation from competitor brands not in a position to label their products as 'safe.'

2.5.4 Broader Impacts of Safety Certification (Supply Chain, Recall, etc. in Figure 2.1, Action 12)

Food safety certification could affect the supply chain in many ways. For example, the use of certification reduces information asymmetries between producers and retailers, and therefore might reduce the need for retailers to integrate backwards to acquire manufacturing facilities. More studies investigating the link between food safety certification and vertical integration in the retail industry are warranted. While studies on the impacts of certification on producers' direct financial and export performance are useful, we suggest investigations into impacts on other measures, such as the incidence of recalls and the performance of industries in government mandatory testing. There is one study touch on the impact on food recalls using a questionnaire, but no research on this topic using empirical analysis yet (Crandall et al., 2017). While the data demands for such questions are greater, examining these will address a fundamental question: does the use of private food safety certification improve the safety of our food supply.

2.6 Conclusion

Retailers and governments have been increasingly relying on private food safety standards to increase food safety since their inception in the early 1990s. Over the same period, food supply chains have become increasingly complex and of a global nature. In this context, we ask, “Does evidence exists on how the system of private food safety standards affects stakeholders in the large food system?”, “What are the interactions that define the system of private food safety standards?”, and “Which interactions have been studied in the academic literature and what is learned from these studies?”, and finally, “Which interactions deserve priority in new research efforts?”. To tackle these questions, we first develop a conceptual framework for the market of private food safety standards, outlining how the key players in the market interact, and then identify 15 interactions that define the system of food safety standards. Based on the defining interactions, we conduct a literature search that found 32 peer-reviewed articles on the private food safety certification market. We review these articles and find that the literature, to date, has overwhelmingly focused on only 2 of the 15 defining interactions. Producer adoption of private standards and the producer impacts of private certification have received significant attention, the other defining interactions identified in our conceptual framework have been largely ignored.

We suggest several key areas for future research, including (1) producer responses to competing standards, (2) consumer perceptions of private food safety certification, (3) competition between certifiers for producers, including empirical investigations of price sensitivity of certification (another paper in the same issue offers some initial evidence that certifier competition might inflate audit grades for the BRC standard (Zheng and Bar, 2021)), and (4) most importantly, whether certification actually improves safety, the intended result of the certification. Other ideas to develop also include (are not limited to): the justification (or limits) of private food safety certifications over public or quasi-public certifications, possible market failure in the private food safety certification market (e.g., grade inflation), strategic adoption of food safety standards (public or private) by new firms seeking to legitimize themselves in the market, the impact of differentiated or harmonized standards on the growth of private certifications as well as on consumer perception of food safety certification, and the future of the equilibrium of standards. We would also like to point out that most of the current literature focuses on the GLOBALG.A.P., and more studies on the other standards are warranted. We are also curious about the future evolution of standards. Will we observe more standards in ten years or only one or two standards surviving?

Table 2.1 Classification, Audit Grades, and Number of Certified Sites of Seven Major Private Food Safety Standards

Full Standard Name (Abbreviation)	Classification	Audit Grades	U.S. Certified Sites (2015)	U.S. Certified Sites (2018)	World Certified Sites (2018)
Global Good Agricultural Practices (GLOBALG.A.P.)	Farming	Pass or Fail	5,006[A]	5,239	153,461
British Retail Consortium Food (BRC)	Manufacturing & production	A-D, D not certified	2,140	2,448	27,511
Food Safety System Certification (FSSC 22000)	Manufacturing & production	Pass or Fail	1,036	1,185	16,498
International Featured Standards (IFS)	Manufacturing & production	Percentage score	–	–	–
International Organization for Standardization 22000 (ISO 22000)	Manufacturing, production & farming	Pass or Fail	210	75[B]	32,722
PrimusGFS	Manufacturing, production & farming	Superior, excellent, good, not certified	8,838	11,713	17,913
Safe Quality Food (SQF)	Manufacturing, production & farming	Excellent, good, compliance, fail	4,357	8,858	11,833

Source: Individual Standards’ websites. BRC and SQF grades are publicly available. A–data are for the year 2016. B–data are for the year 2017. Certified site data for IFS were not available to the public. For example, in 2018, 2,448 manufacturing sites were certified to BRC food safety standards. A manufacturer could have more than one site, certified to the same or different standard.

Table 2.2 Number of Certified Sites in the U.S. by Operation and Product Type for PrimusGFS and BRC

2a. Number of Certified Sites Using PrimusGFS, by Operation Type and by Year

PrimusGFS		
Operation type	2015	2018
Farm (including greenhouses and ranches)	7,061	6,989
Others (Storage, processing, packing, and distribution)	1,777	4,724
Or by		
Good Agricultural Practice (GAP)	7,200	9,396
Good Manufacturing Practice (GMP)	1,638	2,317
Total	8, 838	11,713

2b. Number of Certified Sites Using BRC Standards, by Food Products and by Year

BRC		
Products	2015	2018
Raw red meat	112	112
Raw poultry	216	201
Raw prepared products (meat and vegetable)	378	422
Raw fish products and preparations	97	130
Fruits, vegetables, and nuts	95	113
Prepared fruit, vegetables, and nuts	180	212
Dairy, liquid egg	132	154
Cooked meat/fish products	200	214
Raw cured/or fermented meat and fish	23	28
Ready meals and sandwiches	114	139
Low/high acid in cans/glass	160	160
Beverages	54	59
Alcoholic drinks and fermented/brewed products	32	36
Bakery	366	395
Dried foods and ingredients	506	646
Confectionery	71	90
Cereals and snacks	59	81
Oils and fats	68	82

Note: One site can be involved with more than two products; the sum of each column in table 2b does not reflect the total number of sites that were certified with BRC.

Table 2.3 A Summary Matrix of Selected Studies on Private Food Safety Certification

Author	Researched Country	Data Period	Standards	Products	Observations	Methodology
Andersson (2019)	EU 15 countries	2009-2013*	GLOBALG.A.P.	Fruits & vegetables	193,050*	Gravity model
Annor et al. (2016)	Ghana	2012	GLOBALG.A.P.	Pineapple	150	Probit model
Asfaw et al. (2009) [a]	Kenya	2005-2006	EUREPGAP	Vegetables	439	Structural revenue model; Two-stage standard treatment model
Asfaw et al. (2009) [b]	Kenya	2005-2006	GLOBALG.A.P.	Vegetables	439	Propensity scores matching model; Two-stage standard treatment model
Asfaw et al. (2010)	Kenya	2005-2006	EUREPGAP	Vegetables	439	Financial impact model
Bar and Zheng (2018)	U. S.	2011-2015*	BRC	NA	7,180*	Choice model
Colen et al. (2012)	Senegal	2005-2010	GLOBALG.A.P.	Fruits & vegetables	46	Fixed effect model
Drescher et al. (2009)	192 Countries	2007	BRC; GLOBALG.A.P.	NA	158,829*	Tobit model
Ehlert et al. (2014)	Kenya	2005-2006	GLOBALG.A.P.	Vegetables	100	Multiple indicators and multiple causes model
Ehrich & Mangelsdorf (2018)	European, African, American, and Asian countries	2008-2013*	IFS	Egg products, meat, F&V, bakery products, dairy products, and beverages	1,822,819*	Gravity model
Fiankor et al. (2019)	EU/EFTA	2010-2015*	GLOBALG.A.P.	Fruits & vegetables	120,043*	Gravity model
Gawron & Theuvsen (2009)	Germany	2005	IFS	Confectionery and snacks, meat, milk, bakery products	65	Cluster analysis
Handschuch et al. (2013)	Chile	2008	INDAP GAP	Raspberry	226	Probit model; Linear regression model
Hansen & Trifković (2014)	Vietnam	2011	GLOBALG.A.P., SQF	Pangasius catfish	276	Instrumental variable quantile regression

Table 2.3 (continued)

Henson et al. (2011)	10 sub- Saharan African countries	200 0-2006	GLOBALG. A.P.	Fresh produce	1 02	Probit model; Propensity score matching model
Herzfeld et al. (2011)	188 countries	200 7*	BRC; GLOBALG.A.P.	NA	1 88	Negative binomial model
Holzapfel & Wollni (2014)	Thailand	201 0-2011	GLOBALG. A.P.	Fruits & vegetables	2 87	Probit model; Fixed effect model
Kariuki (2014)	Kenya	200 6	GLOBALG. A.P.	French beans	2 49	Logit model
Kariuki et al. (2012)	Kenya	200 6	GLOBALG. A.P.	French beans	2 49	Random effect model
Kersting & Wollni (2012)	Thailand	201 0	GLOBALG. A.P.	Fruits & vegetables	2 31	Probit model
Kleemann et al. (2014)	Ghana	201 0	GLOBALG. A.P.	Pineap ple	3 86	Endogenous switching model
Latouche & Chevassus-Lozza (2015)	France	200 7*	BRC; IFS	NA	2 ,942*	Propensity score matching model
Lemeilleur (2013)	Peru	201 0-2011	GLOBALG. A.P.	Mango	2 13	Probit model
Lippe & Grote (2017)	Thailand	NA	GLOBALG. A.P.	Orchid & Mango	4 00	Logit model
Mohammed & Zheng (2017)	131 countries	201 3*	All but IFS	NA	7 86	Negative binomial model
Muriithi et al. (2011)	Kenya	200 7	EUREPGAP	French beans	1 03	Probit model
Păunescu et al. (2018)	Romania	201 7	ISO 22000	NA	4 3	Factor analysis
Schuster & Maertens (2013)	Peru	199 3-2011	BRC; GLOBALG.A.P.	Aspara gus	5 67	Fixed effect and GMM model
Schuster & Maertens (2015)	Peru	199 3-2011	GLOBALG. A.P.; SQF; BRC; IFS	Aspara gus	5 67	Fixed effect and GMM model
Seok et al. (2016)	U.S.	201 4*	SQF	All food products	2 8,625*	Poisson pseudo- maximum likelihood model

Table 2.3 (continued)

Souza Monteiro & Caswell (2009)	Portugal	2006	EUREPGAP	Pear	138	Choice model
Subervie & Vagneron (2013)	Madagascar	2009	GLOBALG.A.P.	Lychee	505	Logit model; Difference-in-differences matching model

Table 2.4 Factors that Affect the Adoption of Private Food Safety Certification

Farm-level characteristics		Author (s)
Household characteristics	Education	+ (Asfaw et al., 2009b, 2010; Handschuch et al., 2013; Holzapfel and Wollni, 2014; Kersting and Wollni, 2012; Kleemann et al., 2014; Lemeilleur, 2013; Lippe and Grote, 2017; Souza Monteiro and Caswell, 2009; Subervie and Vagneron, 2013), - (Kariuki, 2014)
	Off-farm activities	+ (Annor et al., 2016; Asfaw et al., 2010), - (Kariuki, 2014; Kersting and Wollni, 2012; Muriithi et al., 2011)
	Age	- (Annor et al., 2016; Holzapfel and Wollni, 2014; Kersting and Wollni, 2012; Kleemann et al., 2014; Souza Monteiro and Caswell, 2009)
	Household wealth	+ (Asfaw et al., 2009b, 2010; Kariuki, 2014; Kersting and Wollni, 2012; Kleemann et al., 2014)
	Household size	- (Kersting and Wollni, 2012), + (Muriithi et al., 2011)
	Experience with contract farming	+ (Asfaw et al., 2009b; Lemeilleur, 2013)
	Experience with high-value supply chain	+ (Kersting and Wollni, 2012; Lippe and Grote, 2017)
	Experience with public standard certificates	+ (Holzapfel and Wollni, 2014; Lippe and Grote, 2017)
	Male household head	+ (Handschuch et al., 2013)
	No. of female household members	+ (Kersting and Wollni, 2012)
	Risk aversion level	+ (Kleemann et al., 2014)
	Awareness about environmental and social requirements	+ (Lippe and Grote, 2017)
Farm characteristics	Farm size	+ (Annor et al., 2016; Asfaw et al., 2010; Handschuch et al., 2013; Kariuki, 2014; Kersting and Wollni, 2012; Kleemann et al., 2014; Lemeilleur, 2013; Lippe and Grote, 2017; Muriithi et al., 2011)
	Farm asset	+ (Kariuki, 2014; Lemeilleur, 2013; Muriithi et al., 2011)
	Irrigation	+ (Asfaw et al., 2009b; Holzapfel and Wollni, 2014; Kariuki, 2014; Kersting and Wollni, 2012)

Table 2.4 (continued)

	Extension service	+ (Annor et al., 2016; Asfaw et al., 2009b, 2010; Holzapfel and Wollni, 2014; Kariuki, 2014; Muriithi et al., 2011; Subervie and Vagneron, 2013)
	Group membership	+ (Asfaw et al., 2009b, 2010; Handschuch et al., 2013; Lemeilleur, 2013; Souza Monteiro and Caswell, 2009), - (Kersting and Wollni, 2012)
Access-related characteristics	Access to market and market information	+ (Annor et al., 2016; Asfaw et al., 2009b; Muriithi et al., 2011; Subervie and Vagneron, 2013), - (Kersting and Wollni, 2012; Lemeilleur, 2013)
	Communication tools (radio, TV, mobile phone)	+ (Asfaw et al., 2009b, 2010; Handschuch et al., 2013; Lemeilleur, 2013)
	Training	+ (Asfaw et al., 2009b; Kersting and Wollni, 2012; Muriithi et al., 2011), - (Lippe and Grote, 2017)
	Access to credit	+ (Asfaw et al., 2009b, 2010)
	Donor or buyer support	+ (Asfaw et al., 2009b; Holzapfel and Wollni, 2014; Kersting and Wollni, 2012; Lemeilleur, 2013)
	No. of exchange seasons	+ (Kariuki, 2014)
Others	Price of products	- (Kariuki, 2014)
	Change in purchaser	- (Subervie and Vagneron, 2013)
Firm-level characteristics		**Article number (s)**
Firm capacity		+ (Henson et al., 2011)
Buyer demand for certification		+ (Henson et al., 2011)
Size of horticulture sector in the country		+ (Henson et al., 2011)
Technical and financial support		+ (Henson et al., 2011)
Country-level characteristics		**Article number (s)**
Economic development		+ (Drescher et al., 2009; Herzfeld et al., 2011; Mohammed and Zheng, 2017)
Infrastructure condition (including certifiers)		+ (Drescher et al., 2009; Herzfeld et al., 2011; Mohammed and Zheng, 2017)
Institutional quality		+ (Drescher et al., 2009; Herzfeld et al., 2011)
Country size		+ (Drescher et al., 2009; Herzfeld et al., 2011)

Note: Insignificant results are not included in the table. (+) or (-) denotes that the factor is either positively or negatively correlated with the adoption of private food safety certification, respectively.

Table 2.5 Impacts of Private Food Safety Certifications

Impact on farmers		Author (s)
Financial performance	Financial rate of return	+ (Asfaw et al., 2009b)
	Revenue or net income	+ (Asfaw et al., 2009a, 2009b, 2010; Handschuch et al., 2013; Holzapfel and Wollni, 2014)
	Consumption expenditure	+ (Hansen and Trifković, 2014)
Market performance	Price received	+ (Kleemann et al., 2014; Subervie and Vagneron, 2013)
	Quantity sold	+ (Handschuch et al., 2013; Subervie and Vagneron, 2013)
Impact on Firms		**Article number (s)**
Firm performance	Firm management and productivity	+ (Gawron and Theuvsen, 2009; Latouche and Chevassus-Lozza, 2015; Păunescu et al., 2018)
Employees	Worker's welfare	+ (Colen et al., 2012; Ehlert et al., 2014)
Impact on industries		**Article number (s)**
Vertical integration		+ (Schuster and Maertens, 2013)
Impact on exports		**Article number (s)**
Export volume		+ (Andersson, 2019; Fiankor et al., 2019; Henson et al., 2011; Seok et al., 2016), × (Schuster and Maertens, 2015)
Export value		+ (Andersson, 2019; Ehrich and Mangelsdorf, 2018; Henson et al., 2011), × (Schuster and Maertens, 2015)

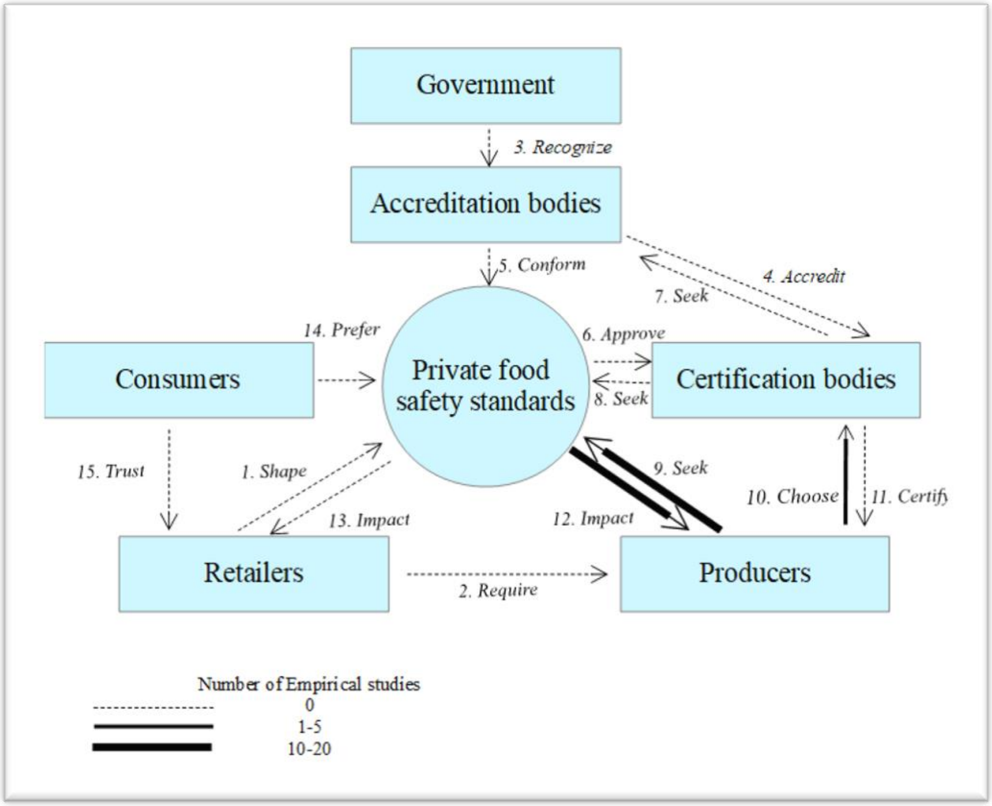

Figure 2.1 A Conceptual Framework of the Private Food Safety Certification Market

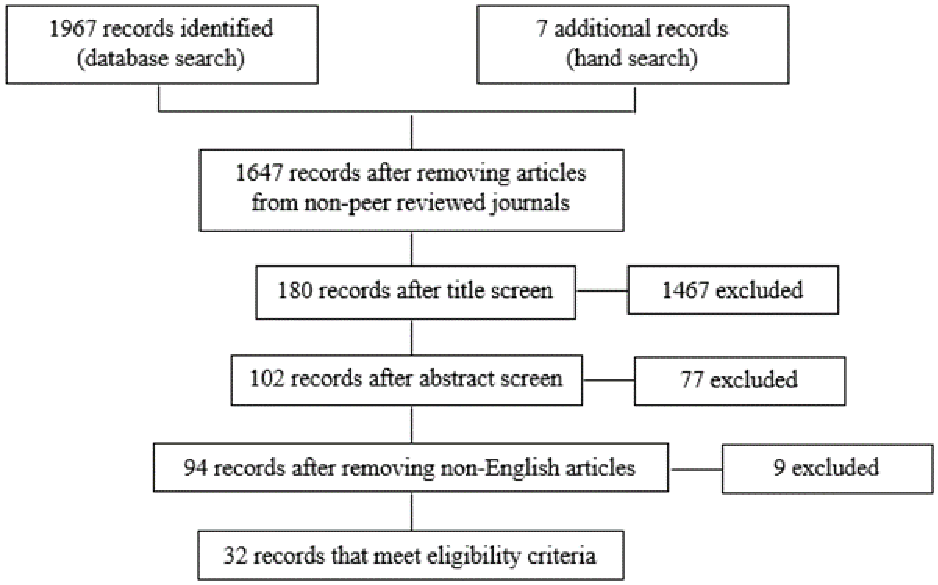

Figure 2.2 Data Collection Process Flow Chart

Figure 2.3 A Product with Private Food Safety Certification Labeling ISO 22000

CHAPTER 3. THE EFFECT OF PRIVATE FOOD SAFETY CERTIFICATION ON FOOD SAFETY OUTCOMES

3.1 Introduction

Food safety has been a serious matter in the United States. Centers for Disease Control and Prevention (CDC) estimates that 48 million people get sick, 128,000 are hospitalized, and 3,000 die from foodborne diseases each year in the United States year (Painter et al., 2013; Scallan et al., 2011a; Scallan et al., 2011b). Additionally, one of the CDC surveillance systems, the Foodborne Disease Outbreak Surveillance System (FDOSS), identified 841 foodborne disease outbreaks, resulting in 14,481 illnesses, 827 hospitalizations, and 20 deaths in 2017 (CDC, 2019). Among these outbreaks, *Salmonella* is the second most common cause (113 cases), followed by Shiga toxin-producing *Escherichia coli* (19 cases). Furthermore, the United States Department of Agriculture, Economic Research Service (ERS) estimates the total economic cost[4] of major foodborne illnesses to be $15.5 billion in 2013 and $17.6 billion in 2018[5].

While consumers have always demanded safe food, supply chains have become increasingly complex and of a global nature. At the same time, the ability to identify factors related to food safety-as well as the ability to communicate these metrics-has increased. Improving the food safety system needs the joint efforts of the government, industry, individuals, and private sector. Over the past two decades, there has been a proliferation of private food safety standards (also known as private food safety management system to the

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[4] Economic cost is calculated by medical care cost, the value of lost earnings, and a monetary measure of death linked to how much people are willing to pay to reduce risk of dying from foodborne illness.

[5] Data source is found at: https://www.ers.usda.gov/amber-waves/2021/april/economic-cost-of-major-foodborne-illnesses-increased-2-billion-from-2013-to 2018/#:~:text=ERS%20recently%20released%20revised%20cost,the%20number%20of%20cases%20constant. Last access on May 17, 2022.

industry) and private entities that certify producers, processors, and manufacturers as having met these standards. Though this new phenomenon has been receiving increasing attention, in general, there is a lack of empirical studies especially about certification's food safety effect on firms or farms. Only one study has investigated the impact of the private sector on food safety outcomes (Adalja et al., 2021). The authors find that adopting food safety guidelines by government-backed organizations [6] (e.g., trade associations and product commissions) improves some food safety outcomes. In this study, we aim to fill the gap in the literature of the private food safety certification market.

We use a unique panel dataset to examine whether private food safety certification makes food systems safer, focusing on the meat, poultry, and egg products industry. We merge multiple datasets, both private and government datasets, to study the effect of private food safety certification on food safety performances. We use test results from the United States Department of Agriculture, Food Safety and Inspection Service (FSIS) sampling programs to measure food safety performances.

Investigating the role of private certification in food safety is particularly informative to policy makers and producers, helping them better allocate resources. From a business perspective, our research will quantify the benefits of certifications and therefore help especially small-scale producers make informed decisions on the certification. From a regulatory standpoint, we can provide policymakers with insights into the complementarity of private food safety certification and mandatory government monitoring. For USDA, our results address a fundamental question regarding the use of a private mechanism in government inspection. How much can private food safety

[6] Government-backed organizations refer to organizations that are overseen by the Agricultural Marketing Service of USDA.

certification be trusted? If private food safety certification indeed improves the food safety outcomes, then the government might utilize certification to optimize the use of budgeted resources. For example, one implication is that the government might benefit from the cost perspective by allocating more inspections to those without food safety certification.

Due to rare event and separation issues in the data, the study adopts the penalized maximum likelihood. When the number of observations for one class of the binary response is much smaller than the number of observations for the other class of the binary response, we have rare events data, also called imbalanced data. One of the consequences of rare events data is the separation issue, where one or more of a model's covariates perfectly predict the outcome variable (Zorn, 2005). When the separation issue exists, traditional maximum likelihood estimates in logistic regression are biased away from zero (Gao and Shen, 2007; Zorn, 2005). Rare event data and separations issues have attracted a lot of attention in the fields like political science (Cook et al., 2020; King and Zeng, 2001; Muchlinski et al., 2016; Rainey, 2016), health and medical science (Böhning et al., 2015; Haem et al., 2015; Hunter, 2015; Lane, 2013; Mansournia et al., 2018; Shuster et al., 2007; Zare et al., 2013), natural hazards (Bai et al., 2011; Guns and Vanacker, 2012; Kim et al., 2014; Nosrati et al., 2018; Van Den Eeckhaut et al., 2006), Geoscience (Vanwalleghem et al., 2008; Veazey et al., 2016; Xiong and Zuo, 2018), and other low-risk accidents studies such as windshear occurrence (Chen et al., 2020), red-light running (Ren et al., 2016), and school shooting (Westphal, 2013).

Based on the literature, penalized maximum likelihood method is suggested for rare events data to solve separation issues (Cook et al., 2020; Heinze and Schemper, 2002; Kim et al., 2014; Lee, 2020; Mansournia et al., 2018; Puhr et al., 2017). It is the optimal choice according to our data structure and our objective. The theoretical basis of penalized maximum likelihood method is to place a penalty on the standard maximum likelihood function. It has the advantage of producing unbiased estimates, even with small samples. Therefore, we apply penalized maximum likelihood method to investigate the impact of private food safety certification on FSIS sampling program pathogen results. Using our dataset from 2015 to 2018, we find links between the British Retail Consortium (BRC) certification and Safe Quality Food (SQF) Certification and food safety outcomes: BRC certification is negatively associated with *Salmonella* and *Campylobacter* test results; SQF certification is negatively correlated with *Campylobacter* and *Lister* test results.

We contribute to the literature in three ways. First, to our knowledge, this is the first study that examines whether the private food safety certification improves food safety outcomes using an econometric method. Second, this study tries to untangle the interaction between the private sector (private food safety certification) and public sector (FSIS sampling) with our unique dataset that combines private and government datasets. Third, this study adds to the literature that adopts penalized maximum likelihood method for rare event and separation issues.

This paper proceeds as follows: section 3.2 discusses the datasets and the data structure. Section 3.3 looks at some of the empirical tools used to analyze panel data with the binary outcome variable and justifies our choice of methodology. Section 3.4 discusses the results. Section 3.5 concludes the findings and provides suggestions for future research.

3.2 Data

We construct a unique dataset that combines private food safety certification data, ReferenceUSA data, FSIS inspection directory, FSIS sampling data, and FSIS Quarterly

Enforcement Data from 2015 to 2018. We merge the FSIS inspection directory, FSIS sampling data, and FSIS Quarterly Enforcement Data using the establishment number assigned by FSIS. Then we match FSIS-related data with private food safety certification data and ReferenceUSA data using establishment names and addresses. Unfortunately, a large portion of establishments from different sources cannot be matched together. There are 6,294 establishments in the FSIS inspection directory, and we successfully match 2,289 of them with other datasets. Match failures occur for three reasons: (1) FSIS inspection directory is from 2019, while our ReferenceUSA data is from 2015 to 2018. Many establishments that were active from 2015 to 2018 may not be active or exist in 2019, thus do not appear on the 2019 inspection directory. (2) ReferenceUSA does not collect information from all the establishments. (3) We could not merge the establishments if they change name or address and do not report it on either ReferenceUSA or FSIS. We compare the establishments in our dataset and in the FSIS dataset, and we find that both datasets have a similar composition in terms of establishment size (mostly small establishments). Therefore, we believe that the unmatched establishments are not systematically missing from our dataset. The data merge yields a dataset with a total of 215,744 observations for which the certification status, scope, sales volume, FSIS enforcement action information, and FSIS sampling results of the establishments are known.

3.2.1 Private Food Safety Certification Data

As mentioned in chapter one, there are seven internationally accepted collective standards, including Global Good Agricultural Practices (GLOBALG.A.P.), British Retail Consortium Food (BRC), Food Safety System Certification (FSSC 22000)[7], International

[7] For simplicity, we refer FSSC 22000 as FSSC in the tables.

Featured Standards (IFS), International Organization for Standardization 22000 (ISO 22000), PrimusGFS, and Safe Quality Food (SQF). The purpose of private food safety standards is to harmonize food safety standards across the supply chain and build confidence in the food supply chain. Of the seven standards, BRC, FSSC 22000, and SQF offer food safety certifications to meat, poultry, and egg establishments[8]. The Global Food Safety Initiative (GFSI) was founded in May 2000 to benchmark food safety schemes. BRC, FSSC 22000, and SQF are all recognized standards by the Global Food Safety Initiative (GFSI) and offer certifications to all sectors of the food supply chain.

BRC was founded in the United Kingdom in 1996. FSSC 22000 is based in the Netherlands and has representatives in North America, South America, India, Japan, and a liaison in China. GFSI has given FSSC 22000 full recognition since 2010. SQF was first developed in Australia in 1994 and then was recognized by GFSI in 2004. SQF is now a US-based standard, whereas BRC and FSSC 22000 are Europe-based. Table 3.1 shows the number of establishments certified with BRC, FSSC 22000, and SQF in the meat, poultry, and egg products industry. SQF and BRC are the two major players in the private food safety certification market in the industry in the United States. SQF alone takes around 58% of the market share, and it has an increasing trend. BRC takes approximately 37% of the market share, while FSSC 22000 only takes 4%.

The number of certified establishments are 864, 968, 931, and 1,072 in the year 2015, 2016, 2017, and 2018, respectively. Correspondingly, the total number of establishments in our dataset is 2,090, ,2186, 2,233, and 2,289. Therefore, the proportion of certified establishments is 41%, 44%, 42%, and 47%.

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[8] Currently, we do not have access to IFS data.

3.2.2 ReferenceUSA Data

ReferenceUSA provides annual establishment-level characteristics data, such as sales volume. Annual sales volume is classified into eleven ranges (as a multiple of $1,000): 1 – 499,999; 500,000 – 999,999; 1,000,000 – 2,499,999; 2,500,000 – 4,999,999; 5,000,000 – 9,999,999; 10,000,000 – 19,999,999; 20,000,000 – 49,999,999; 50,000,000 – 99,999,999; 100,000,000 – 499,999,999; 500,000,000 – 999,999,999; over 1 billion[9]. Table 3.2 shows the number of establishments by annual sales volume and year. On average, 10% of establishments have annual sales volume less than 500 dollars, 50% of establishments have annual sales volume less than 10,000 dollars, and 80% have annual sales volume less than 50,000 dollars.

Annual sales volume data for an establishment varies on a small scale from year to year. We calculate the mean and standard deviation and display them in Table 3.3. Over 98% of variation comes from between variation rather than within variation, demonstrating that annual sales volume at the establishment level does not vary significantly from 2015 to 2018. The mean and standard deviation for certification status and test results are shown in Table 3.3 as well. For BRC, SQF, and FSSC 22000, most variations come from between variations, which indicates that establishments do not change certification status much during the observed period.

3.2.3 Meat, Poultry, and Egg Product Inspection Directory

The Meat, Poultry, and Egg Product Inspection (MPI) Directory provides a list of official establishments regulated by FSIS that produce meat, poultry, and/or egg products.

[9] Annual sales volume is always modeled.

An official establishment, determined by USDA Secretary or FSIS Administrator, is where inspection is maintained following regulations for the slaughter of meat or poultry animals or processing of meat or poultry food products (FSIS, 1992). The Directory is updated monthly; we use the version from April 2019.

In addition, this Directory provides establishment scope information, whether the establishment is involved in meat, poultry, egg, import, and/or export activities. We summarize the scope of the establishments in table 3.4. The number of egg and import establishments stays relatively stable, while the number of establishments in meat, poultry, and export industries increases gradually throughout the years.

3.2.4 FSIS Sampling Data

The U.S. Department of Agriculture has a long, rich history of improving and protecting America's food supply. The USDA inspection services began in 1890 to inspect salted pork and bacon for exportation and expanded to all live cattle and beef products the following year. In 1906, the Federal Meat Inspection Act (FMIA) became law and prohibited the sale of adulterated or misbranded meat products to ensure that meat products are slaughtered and processed under sanitary conditions. Inspection service has evolved over time, especially with the passing of the Federal Meat Inspection Act (FMIA) and the growth of the meat industry. In response to the public's demand for safer products, FSIS issued Pathogen Reduction/HACCP systems, starting a microbiological testing program to detect *E. coli* in 1996. Nowadays, FSIS tests for five pathogens, including *E. coli*, *Campylobacter*, *Listeria Monocytogenes*, *Salmonella*, and non-O157 STECs[10] on various

[10] FSIS tests six Shiga toxin-producing Escherichia coli (STEC) in raw, non-intact beef products or the components of these products. These six non-O157 STECs are O26, O45, O103, O111, O121, and O145.

FSIS-regulated products. FSIS routinely collects sampling and conducts microbiological testing from regulated establishments to verify that establishments operate according to food safety regulations, policies, and performance standards. In addition to sampling on regulated establishments, FSIS posts these data on the FSIS website, including establishment-specific data and sampling results data. We collect sampling data and establishment data from the FSIS website.

Descriptive data for sampling are summarized in table 3.5. In our dataset, sampled products include raw beef (raw beef components, raw-ground-beef or otherwise RGB, and beef trim), raw chicken (chicken carcass, chicken parts, comminuted or otherwise nonintact chicken), raw turkey (turkey carcass), processed egg, and ready-to-eat (RTE) products. A testing program to detect *E. coli* O157:H7 in raw beef products started in October 1994. In addition to *E. coli* O157:H7, FSIS considers raw beef products with six other Shiga toxin-producing *E. coli* (STEC) to be adulterated. These six non-O157 STECs are O26, O45, O103, O111, O121, and O145. FSIS began testing for these non-O157 STECs on beef manufacturing trimmings in June 2012. FSIS has conducted a regulatory *Listeria* testing program in RTE products since 1983 and started random testing in 1990 (FSIS, 2022). Currently, FSIS samples randomly to detect *Listeria* on all RTE and processed egg products. Further, FSIS collects *Salmonella* samples in all raw beef, raw turkey, raw chicken, RTE, and egg products and collects *Campylobacter* samples in all raw turkey and raw chicken products. In fact, all samples collected for raw chicken and raw turkey are both analyzed for both *Campylobacter* and *Salmonella*.

From 2015 to 2018, 43,103 samples were taken for *E. coli* testing, 89,916 samples were taken for *Salmonella*, 33,518 samples were taken for *Listeria*, 40,246 samples were taken for *Campylobacter*, and 8,961 samples were taken for non-O157STECs, resulting in a total of 215,744 samples. Overall, *Salmonella* and *Campylobacter* have high positive rates, 5.06% and 3.65%, while *E. coli*, *Listeria*, and non-O157STECs have relatively low positive rates.

The sampling procedure and frequency are subject to the type of pathogen tested. For *Salmonella* and *Campylobacter*, sampling is conducted in the form of sets (FSIS, 2021). Inspection program personnel (IPP) assigned to establishments collect product samples by sample sets. A sample set is pre-defined by IPP based on production volume. In general, establishments with higher production volumes will likely to be collected more samplings than establishments with lower volumes. It takes two months to over a year to complete a sample set. During the period of a sample set, sampling is conducted daily on the establishments. The sampling results dataset for *Salmonella* and *Campylobacter* is unbalanced for four reasons. First, the definition of a set implies that multiple samples could be collected in an establishment on the same day. Second, the sampling schedule decides that establishments are sampled intensively for a while and then not at all for the rest. Third, eligible establishments could enter the sampling programs, and ineligible establishments may exit the programs due to seasonal processing, closure, change in business practices, or other reasons. Four, FSIS excludes certain establishments from sampling programs for a period. For example, establishments with *Salmonella* results at 50% or less of the performance standard in the two most recently completed sample sets are exempted from the sampling for *Salmonella* for up to two years (FSIS, 2021b).

For *E. coli*, non-O157 STECs, and *Listeria*, FSIS randomly chooses a certain number of active establishments every month to conduct sampling on a weekly basis (FSIS, 2015; FSIS, 2022). Like *Salmonella* and *Campylobacter* sampling, sampling size is likely to correlate with production volume. Sampling result datasets for these three pathogens are unbalanced as well. The unbalance may result from sampling selection, eligibility of new establishments, or ineligibility of establishments.

We summarize the number of establishments by annual sampling frequency and year in table 3.6. The annual sampling frequency includes sampling for all types of pathogens. The four columns under 2015, 2016, 2017, and 2018 represent the number of establishments by the range of annual sampling frequency in the year 2015, 2016, 2017, and 2018, respectively. For instance, 733 establishments were sampled between 1 and 10 times in the year 2015. The range for annual sampling frequency is between 1 and 355. The column "Total" is the number of establishments responding to each annual sampling frequency range, summed over the year 2015 to the year 2018. The last column of this table is the cumulative percentage of the number of establishments according to the increasing annual sampling frequency. It reveals that most of the establishments, 70% of them, are sampled less than 20 times, and 90% of them are sampled less than 50 times. The number on the bottom row of this table for columns 2015 to 2018 represents the total number of establishments sampled each year. The number of establishments in this dataset stays relatively stable, around 2,000 each year.

As mentioned earlier, production volume is one key factor determining sampling frequency. We do not have data on production volume; however, we have sales volume data from ReferenceUSA. We illustrate the number of establishments by sales volume and by sampling frequency for the year 2018 in table 3.7. When the annual sampling frequency is between one to ten, the number of establishments decreases as sales volume increases.

However, when the annual sampling frequency is between 101-355, the number of establishments increases as sales volume increases. It is consistent with the statement that sampling frequency will likely increase as sales volume (production volume) increases.

3.2.5 Quarterly Enforcement Data

An establishment needs to have a validated food safety system that aligns with regulations to operate. The food safety system required for meat, poultry, or/and egg product establishments is the Hazard Analysis and Critical Control (HACCP) system (FSIS, 2021a). The HACCP system consists of the establishment's plans, programs, measures, and procedures to prevent, eliminate, or otherwise control identified food safety hazards. This system lays the foundation of the establishments' food safety system. The regulations also require that the establishments maintain Sanitation SOPs and meet the SPS requirements. Sanitation SOPs are a prerequisite to the HACCP plan and cover daily procedures that the establishments take before and during operations to prevent products from being contaminated and adulterated. The SPS regulations cover all the other aspects of establishment sanitation that can affect food safety, for example, pest control and ventilation. Establishment activities that are covered by Sanitation SOPs and SPS overlap sometimes. HACCP system, Sanitation SOPs, and SPS are three essential elements that form an establishment's food safety system to prevent contaminated products from entering commerce. IPP file a non-compliance if an establishment fails to meet any regulatory requirement. When there are two or more non-compliances filed on an establishment, enforcement actions will take place. Enforcement actions are in the forms of regulatory control action, withholding, or suspension.

FSIS Quarterly Enforcement Report provides a summary of the enforcement actions taken at the establishments. Enforcement actions may be due to HACCP non-compliance, Sanitation SOPs non-compliance, SPS non-compliance, inhumane treatment/slaughter, and/or interference/assault. We focus on enforcement actions that affect establishments' food safety system, that is, enforcement actions caused by HACCP non-compliance, Sanitation SOP non-compliance, and/or SPS non-compliance.

Table 3.8 demonstrates the number of enforcement actions taken at the establishments by year and quarter. In this study, quarter one is defined as January, February, and March; quarter two includes April, May, and June; Quarter three includes July, August, and September. Quarter four includes October, November, and December. The number of enforcement actions displays a seasonal pattern, where fewer enforcement actions are taken in quarter four each year. We use this data to represent an establishment's "quality".

After combining all datasets, we obtain a dataset that has manufacture-level test results from FSIS sampling, "quality", certification status, sales volume, and scope from 2015 to 2018. The objective of this study is to see whether private food safety certification has an impact on FSIS sampling results. We provide a statistical summary of the number of establishments by certification status, test results, and year for *Salmonella*, *Campylobacter*, *E. coli*, non-O157 STECs, and *Lister* in tables 3.9, 3.10, 3.11, 3.12, and 3.13, respectively. "Negative" indicates that the establishments have no positive results for the pathogen in the year; "positive" indicates that the establishments have at least one positive result for the pathogen in the year. Taking *Salmonella* as an example, the number 1,303 means that there are 1,303 establishments in 2015 that have no positive test results for *Salmonella* and have no private food safety certification, as shown in table 3.10. The data summary is very informative. Taking another example with *E. coli*, the number between “Positive” and “BRC” in 2015 is zero as shown in table 3.12, which represents that there are no establishments that have positive test results and have BRC certification at the same time. From tables 3.11, 3.12, and 3.13, we observe that the numbers between “Positive” and “BRC” or “SQF” or “FSSC” are very low, even zero for many. These numbers imply that we might not be able to find a link between test results (*E. coli*, non-O157 STECs, and *Lister*) and private food safety certifications.

3.3 Model and Results

We are interested in the relationships between private food safety certification and pathogen test results from FSIS sampling programs. The general form of the model we would like to estimate is as follows:

$$y_{it} = \beta_0 + \beta_1 x_{1t} + \beta_2 x_{2t} + \cdots + \beta_k x_{kt} + \varepsilon_{it} = x_{it}'\beta + \varepsilon_{it} \quad (1)$$

Equation (1) specifies that the dependent variable y_{it} is a function of k explanatory variables. Given that the dependent variable is a binary variable, we will start will a basic logit model. With logit model, we have:

$$P(y_{it} = 1 | x_{it}, \beta) = \pi_{it} = \mathrm{F}\,(x_{it}'\beta) = \frac{1}{1+e^{-x_{it}'\beta}} \quad (2)$$

Where $F(\cdot)$ is the cumulative distribution function of μ_{it} for a logit model. This equation indicates that the probability of having $y_{it} = 1$ depends on the vector x_{it} containing individual characteristics. The parameters are estimated by maximum likelihood, with the likelihood function formed as:

$$\ln L(\beta|y) = \sum_{y_{it}=1} \ln(\pi_{it}) + \sum_{y_{it}=0} \ln(1-\pi_{it}) = -\sum_{i=1}^{n} \ln(1+e^{(1-2y_{it})x_{it}\beta})$$

(3)

The first derivative vector, or score vector, is given by:

$$U(\beta) = \frac{\partial \ln L(\beta|y)}{\partial \beta} = \sum_{i=1}^{n} \frac{\partial \ln f(y_{it}|\beta)}{\partial \beta} = \sum_{i=1}^{n} (y_{it} - \pi_{it})x_{it} = 0 \quad (4)$$

We can obtain the information matrix as minus the expected value of the second derivatives of the loglikelihood:

$$I(\beta) = -E\left[\frac{\partial^2 \ln L(\beta|y)}{\partial \beta \partial \beta'}\right] \quad (5)$$

When analyzing panel data with binary dependent variables, researchers often select between pooling, random effects (RE), and fixed effects (FE) models. Pooled logit model does not recognize the panel structure of data; thus, the pooled logit model is the usual cross-section model. And it assumes no unobserved unit heterogeneity. The logit FE and RE models recognize panel structure, thus, includes individual effects. The logit individual-effects model specifies that:

$$P(y_{it} = 1|x_{it}, \beta, \alpha_i) = F(x'_{it}\beta + \alpha_i) \quad (6)$$

where α_i represents individual effects, and it may be a fixed effect or random effect. The logit RE model specifies that $\alpha_i \sim N(0, \sigma_\alpha^2)$, which means that the random effect model requires that any unit heterogeneity is orthogonal to the explanatory or unrelated to the explanatory variables. The logit FE model relaxes this assumption, allowing for unobserved time-invariant individual heterogeneity with an arbitrary distribution. Besides, The FE model has the advantage of controlling unobserved time-invariant individual characteristics that may influence the dependent variable. The strong assumption by the logit RE model is hard to achieve. However, researchers still prefer either pooled logit or logit RE model and avoid FE models (Cook et al., 2020). FE estimator suffers from the incidental parameters problem when T is small, resulting in biased estimates even for conditional FE logit models. We can conduct the Brusch-Pagan LM test to compare Pooled logit, and RE logit models. The rejection of the null hypothesis of the LM test indicates that the random effect model is better. We can conduct an F-test to compare Pooled logit and FE logit models. The rejection of the null hypothesis suggests that the FE model is favored. We can conduct the Hausman test to compare RE and FE logit models. If the null hypothesis is rejected, FE logit model is preferred (Park, 2011).

Based on our data structure, we have a rare events issue, which makes pooled, RE, or FE less ideal for this analysis. The rare events issue occurs when the number of events is significantly smaller than the number of no-events. In this study, the event refers to the positive test results, and no-event refers to the negative results. The percentage of positive rate in our datasets varies by the type pathogen, ranging from 0.06% to 5.06%. Even with the highest percentage, 5.06% for *Salmonella,* the probability of positive results is still very low.

One consequence of rare events is separation. With rare event, the maximum likelihood estimation of the logit model suffers from small-sample bias. Separation occurs when one or more of a model's covariates always or never occur with the outcome variable event. It implies that there is a subsector $x_s \subseteq x$ by which all N observations can be categorized as either $y_{it} = 0$ or $y_{it} = 1$. Consequently, the observations that do not experience the event do not enter the log-likelihood. That is, parameter estimates are produced using only the data from the event-experiencing set of observations. With rare event and separation, the maximum likelihood estimation of the logit model suffers from small-sample bias. Several studies demonstrate maximum likelihood estimates are biased away from zero; thus, the probability of $y_{it} = 1$ tends to be underestimated (Heinze and Schemper, 2002; King and Zeng, 2001; Zorn, 2005).

The literature has provided a comprehensive comparison of options to address separation or rare events issues (Heinze and Schemper, 2002; Zorn, 2005). Evidence suggests that the Panelized maximum likelihood method is superior to its alternatives in the presence of separation. Penalized maximum likelihood, also called Firth Method, has the advantage of producing a finite, consistent estimate of regression parameters when the separation issue occurs. In 1993, Firth proposed a modification of the score equation in order to mitigate the small sample bias in generalized models. Subsequently, this method was shown as an effective tool for solving the separation issue in logistic regression (Heinze and Schemper, 2002). The intuition of penalized maximum likelihood approach is to introduce a bias term into the standard likelihood function. Following Zorn (2015) and Heinze and Schemper (2002), the penalized likelihood function is given by:

$$L(\beta|y)^* = L(\beta|y)||I(\beta)|^{\frac{1}{2}} \quad (7)$$

The penalty function $|I(\beta)|^{\frac{1}{2}}$ is known as the Jeffreys invariant prior. With corresponding log-likelihood:

$$\mathrm{lnL}(\beta|\mathrm{y})^* = lnL(\beta|y) + 0.5ln|I(\beta)| \quad (8)$$

where $|I(\beta)|$ is the information matrix; the score function is then replaced with:

$$U(\beta) = \sum_{i=1}^{n}(y_{it} - \pi_{it})\, x_{it}\left(1 + \frac{h_{it}}{2}\right) + \sum_{i=1}^{n}(1 - y_{it} - \pi_{it})x_{it}(\frac{h_{it}}{2}) = 0 \quad (9)$$

Where the h_i are the diagonal elements of the penalized-likelihood version of the standard "hat" matric H:

$$H = w^{\frac{1}{2}}x(x'wx)^{-1}x'w^{\frac{1}{2}} \quad (10)$$

The Firth method split the observations i into two new observations with response values y_i and $1 - y_i$ and updated weights $1 + \frac{h_i}{2}$ and $\frac{h_i}{2}$, thus eliminating the separation problem (Heinze and Schemper, 2002). It guarantees the existence of estimates by removing the first-order bias at each iteration step (Gao and Shen, 2007). With penalized estimation, we are able to maintain the full sample. At the same time, as the number of observations goes to infinite, the penalty term converges towards zero, and the results return to the usual maximum likelihood estimates.

We conduct pooled logit, logit RE, logit FE, and PML models for five pathogens sampling results. Pooled logit, logit RE, logit FE models are performed to illustrate the existence of the separation issue caused by rare event.

In this study, the specification we would like to model is given by:

$$y_{itmys} = \beta_0 + \beta_1 BRC_{iy} + \beta_2 SQF_{iy} + \beta_3 FSSC_{iy} + \beta_4 Lagged\ Enforcement_{i(y-1)} + \beta_5 Sales\ Volume_{iy} + \theta_i + \varphi_{it} + \delta_s + \gamma_y + \varepsilon_{itmys}$$

(11)

where i represents establishment; t represents date; m represents month; y represents year; and s represents State.

The dependent variable is the pathogen test result from FSIS sampling programs. There are multiple samples taken for establishments, even multiple on the same day for many establishments, which yields repeated observations in our panel. We transform the data to one observation each day for an establishment, where one represents there is at least one positive testing result on that day, and zero represents no positive testing results that day. Explanatory variables include certification status, sales volume, lag of enforcement actions taken, establishment scopes (whether the establishment is involved in meat, poultry, egg products, import, or export activities), and tested product dummy variables. The variable lagged enforcement measures an establishment's "quality". The establishments' "quality" can correlate with certification status and sampling results. Intuitively, an establishment with lower "quality" is more difficult to obtain a private certification and is more likely to get tested positive for a pathogen test. Without controlling for "quality", it causes the endogeneity issue. Enforcement action is an enforced action taken by FSIS, and it happens when there are reasons for IPP to believe that the establishments' food safety system is compromised. It is a much more comprehensive indicator than a single accident of positive results for a pathogen. We use a lagged variable for enforcement action in the regressions. Additionally, many types of pathogenic microorganisms exhibit seasonal patterns. Therefore, we include month and year as control, δ_s and γ_y. Furthermore, we add state dummy variables, δ_s, to control demographic patterns.

We expect establishments with private food safety certifications to be less likely to be tested positive for pathogens. Intuitively, private food safety standards are supposed to be stricter than the public regulations, HACCP in this case. Thus, establishments with private food safety certifications will have a better food safety system and perform better in the FSIS pathogen sampling programs.

3.4 Results

Regression results for *Salmonella, Campylobacter, E. coli*, non-O157 STECs, and *Listeria* are presented in tables 3.14, 3.15, 3.16, 3.17, and 3.18, respectively. For each pathogen, we perform pooled logit regression, RE logit, FE logit, and penalized maximum likelihood regressions.

We begin by analyzing the existence of separation. The bottom row of the five tables shows the number of observations in the regressions. As we notice, the number of observations is not consistent across different approaches. In general, fewer observations enter the regressions for pooled logit model, RE logit model, and much fewer for FE logit model. In fact, many observations drop due to the failure of imperfect prediction. Taking regression results for *Salmonella* as an example, the row for the number of observations indicates that 61,464 observations are used for pooled logit and RE model and only 34,443 observations for FE model. However, we have 64,679 observations in total for the analysis of *Salmonella*. The difference in the number of observations between FE model and Firth approach is substantial. This pattern stays valid for all the regression results of the five pathogens. It is noted that this is how some software packages (e.g., Stata) deal with separation, automatically omitting variables and dropping observations from the analysis (Zorn, 2005). In the case of non-O157 STECs, SQF and FSSC 22000 are omitted for pooled, RE, and FE models, whereas they successfully enter the regression for the Firth method.

Another indication of separation is the magnitude of the estimates and standard errors. Traditional maximum likelihood estimates are biased away from zero with separation. From tables 3.14, 3.15 and 3.16, we find that the estimates for our key variables, BRC, SQF, and FSSC 22000, are smaller in absolute value for pooled logit, RE, and FE models than for Firth models. In addition, the standard errors using the Firth method are much smaller than the other three approaches. Comparing results from the Firth method and other methods, we find that Pooled logit yields similar results with the Firth method. For RE and FE models, we see cases where they have opposite signs with Firth estimates.

For example, The RE and FE estimates for BRC are positive for *Salmonella*, while the Firth estimates are negative. Even though Pooled logit and Firth method yield similar results, they show different significant levels and standard errors. For *Campylobacter*, the coefficient of SQF from pooled logit is not significant, but it is significant from the Firth method. Therefore, we find evidence that we have separation issues in our data resulting from rare events. From this point, we will analyze the results from the Firth method.

For *Salmonella*, we find that BRC certification, sales volume, and the establishments involved in exporting activities are negatively associated with test results, while tested products like turkey, chicken, and beef are positively associated with test results compared to RTE products. For *Campylobacter*, BRC, SQF, last year's enforcement action taken by FSIS, and turkey products are found to be negatively associated with test results. For *Listeria*, SQF is negatively correlated with test results, while lagged enforcement action is positively correlated with test results. For *E. coli* and *non-O157 STECs*, we do not find a significant relationship between private food safety certification and test results; only establishment scope, such as whether the establishment is involved in the export activity or egg products, is found to be significant.

Our key variables are BRC, SQF, and FSSC 22000, the three variables that represent private food safety certification status. In table 3.19, we present the estimated average marginal effects of the Firth method for five pathogens. Consistent with our prediction, we find that BRC is negatively associated with *Salmonella*, *Campylobacter*, and *Listeria* test results, though the magnitude of the average marginal effect is small. For instance, the probability of being tested positive decreases by 0.3 percent for *Salmonella* if establishments are certified with BRC and decreases by 2 percent for *Campylobacter* if establishments are certified with BRC.

To check for the robustness of our results, we replace BRC, SQF, and FSSC 22000 status with last year's BRC, SQF, and FSSC 22000 status. Table 3.20 displays the average marginal effects of our key variables. BRC is still significant and negatively associated with *Salmonella*, and *Campylobacter* test results. SQF is also significant and negatively associated with *Campylobacter* and *Listeria* test results.

3.5 Conclusion

We empirically explore the effects of private food safety certification on food safety performance in the meat, poultry, and egg products industry using FSIS pathogen sampling results as the measurement for food safety performances. This is the first try in the literature to reveal how the private food safety certification market interacts with the government-regulated food safety system. Our conceptual framework examines the effects of private food safety certification status, annual sales volume, establishment scope, and product types on FSIS pathogen test results. Since we have rare events data and separation issues, we apply penalized maximum likelihood method to address the problems. First, we illustrate the presence of separation by comparing results from pooled logit, RE logit, FE logit, and penalized maximum likelihood models; and we find evidence to support that the estimates from the traditional maximum likelihood approach are biased from zero. In other words, we show that maximum likelihood estimates are underestimated with the presence of separation, which is consistent with previous studies. Therefore, we prefer the results from penalized maximum likelihood estimation.

Second, we have mixed findings regarding the effect of private food safety certifications; the results differ across pathogen and certification types. Adoption of BRC certification results in food safety improvements in *Salmonella* and *Campylobacter* test results, while adopting SQF certification results in food safety performance improvement in *Campylobacter* and *Listeria* tests. The results are robust to changes where we replace certification status with last year's certification status. Though the marginal effect is small, the finding itself is not trivial. Given the complexity of an establishment's food safety system and the food supply chain, the weak linkage between BRC, SQF, and food safety outcomes has enormous implications for both establishments and the government.

Our results create incentives for establishments to adopt a private food safety certification, preferably BRC or SQF, to improve food safety outcomes and eventually help reduce economic costs caused by food safety incidents if the adulterated products go into commerce. From the establishment's point of view, the benefits of adopting a private food safety certification outweigh the costs. Whenever a food safety incident occurs, an establishment faces expenses from conducting recalls and the costs caused by reputation damage. From society's point of view, adopting a private food safety certification helps guarantee the safety of the food supply chain, thus the health of the public. This study also provides meaningful insights into how the private food safety market works along with the government food safety system. We have partial evidence that the private food safety certification sector operates as complementary to the government's food safety regulations. Furthermore, our results imply that government could allocate more inspections to those without food safety certifications in *Salmonella* and *Campylobacter* sampling programs.

In future work, we plan to expand on this analysis in two ways. First, even though we include a measurement for the establishment's "quality", we still have endogeneity concerns. We will work on an instrumental variable for certification as a robust check for our results presented in this study. Second, we will extend our analysis to explore other industries, such as fresh fruit and vegetables, where food safety incidences frequently occur.

Table 3.1 The Number of Establishments Certified with BRC, SQF, FSSC 22000 by Year

Certification Type	2015	2016	2017	2018
SQF	496	557	513	686
BRC	335	373	378	342
FSSC 22000	33	38	40	44
Total	864	968	931	1,072

Table 3.2 The Number of Establishments by Annual Sales Volume (As a Multiple of $1,000) and Year

	Year				
Annual Sales Volume	2015	2016	2017	2018	Total
1	114	144	217	227	702
2	162	163	195	210	730
3	256	270	285	308	1,119
4	247	259	265	256	1,027
5	267	274	312	314	1,167
6	303	304	260	274	1,141
7	293	306	256	268	1,123
8	144	156	169	160	629
9	253	262	229	223	967
10	31	30	24	31	116
11	20	18	21	18	77
Total	2,090	2,186	2,233	2,289	8,798

Note: Annual sales volume represents a range of estimated annual sales volume at that location. 1: 1 – 499,999; 2: 500,000 – 999,999; 3: 1,000,000 – 2,499,999; 4: 2,500,000 – 4,999,999; 5: 5,000,000 – 9,999,999; 6: 10,000,000 – 19,999,999; 7: 20,000,000 – 49,999,999; 8: 50,000,000 – 99,999,999; 9: 100,000,000 – 499,999,999; 10: 500,000,000 – 999,999,999; 11: Over 1 billion.

Table 3.3 Statistical Summary by Variables and Pathogens

Variables		*Salmonella*	*Campylobacter*	*Listeria*	*E. coli*	non-O157 STECs
Test Results	overall	0.22	0.18	0.05	0.02	0.08
	between	0.09	0.11	0.02	0.00	0.03
	within	0.20	0.17	0.05	0.02	0.07
Sales Volume	overall	2.76	2.50	2.47	2.72	3.18
	between	2.49	2.52	2.42	2.25	2.25
	within	0.57	0.59	0.54	0.55	0.50
BRC	overall	0.45	0.50	0.29	0.39	0.44
	between	0.30	0.43	0.27	0.23	0.23
	within	0.13	0.17	0.07	0.11	0.14
SQF	overall	0.39	0.37	0.43	0.29	0.22
	between	0.34	0.32	0.37	0.24	0.11
	within	0.13	0.12	0.15	0.09	0.09
FSSC 22000	overall	0.10	0.06	0.10	0.11	0.16
	between	0.09	0.08	0.09	0.08	0.07
	within	0.02	0.00	0.02	0.03	0.04

Table 3.4 The Number of Establishments by Scope and Year

Establishment Scope	Year				
	2015	2016	2017	2018	Total
Meat	1,930	2,020	2,061	2,112	8,123
Poultry	1,742	1,820	1,844	1,909	7,315
Egg	34	35	35	34	138
Export	445	472	494	496	1,907
Import	3	3	3	4	13

Note: One establishment can be involved in more than one of the above activities. For example, an establishment can do both meat and poultry processing.

Table 3.5 Descriptive Data for Sampling Programs by Pathogen

Pathogen	Species	Number of Establishments	Number of samples	Number of positive	Positive Rate
E. coli	Raw beef	1,094	43,103	27	0.06%
Salmonella	Raw beef, raw turkey, raw chicken, egg, RTE	2,539	89,916	4,550	5.06%
Listeria	RTE, egg	1,534	33,518	83	0.25%
Campylobacter	Raw turkey, raw chicken	423	40,246	1,470	3.65%
Non-O157STECs	Raw beef	371	8,961	53	0.59%

Table 3.6 The Number of Establishments by Annual Sampling Frequency and Year

Annual Sampling Frequency	Year 2015	2016	2017	2018	Total	Cumulative Percentage (%)
1-10	733	716	721	968	3,138	35.67
11-20	774	828	695	853	3,150	71.47
21-30	275	264	411	166	1,116	84.16
31-40	84	82	101	64	331	87.92
41-50	41	51	60	32	184	90.01
51-60	36	33	38	21	128	91.46
61-70	20	36	25	17	98	92.58
71-80	23	19	19	16	77	93.45
81-90	31	13	12	21	77	94.33
91-100	22	9	12	13	56	94.96
101-200	51	103	97	113	364	99.10
201-355	0	32	42	5	79	100.00
Total	2,090	2,186	2,233	2,289	8,798	100.00

Table 3.7 The Number of Establishments by Annual Sampling Frequency and Annual Sales Volume in 2018

Annual Sampling Frequency	Annual Sales Volume											Total
	1	2	3	4	5	6	7	8	9	10	11	
1-10	127	117	154	127	155	107	105	42	29	5	0	968
11-20	75	59	122	89	110	126	110	75	83	4	0	853
21-30	10	22	18	26	26	17	23	9	13	0	2	166
31-40	4	3	6	3	11	4	11	8	12	2	0	64
41-50	4	1	2	3	2	5	2	5	6	1	1	32
51-60	0	3	1	2	1	2	3	3	5	1	0	21
61-70	0	1	2	2	3	2	1	1	4	0	1	17
71-80	0	0	0	1	0	4	5	1	5	0	0	16
81-90	1	0	1	0	1	3	0	6	7	2	0	21
91-100	0	1	0	0	2	1	1	0	6	1	1	13
101-355	6	3	2	3	3	3	7	10	53	15	13	118
Total	227	210	308	256	314	274	268	160	223	31	18	2,289

Note: Annual sales volume represents a range of estimated annual sales volume at that location. 1: 1 – 499,999; 2: 500,000 – 999,999; 3: 1,000,000 – 2,499,999; 4: 2,500,000 – 4,999,999; 5: 5,000,000 – 9,999,999; 6: 10,000,000 – 19,999,999; 7: 20,000,000 – 49,999,999; 8: 50,000,000 – 99,999,999; 9: 100,000,000 – 499,999,999; 10: 500,000,000 – 999,999,999; 11: Over 1 billion.

Table 3.8 The Number of Enforcement Actions by Year and Quarter

	Year				
Quarter	2015	2016	2017	2018	Total
1	7	13	16	18	54
2	21	24	20	10	75
3	18	14	11	9	52
4	12	11	6	0	29
Total	58	62	53	37	210

Table 3.9 The Number of Establishments by Certification Status, *Salmonella* Test Results and Year

Test Results	2015		2016		2017		2018	
	Negative	Positive	Negative	Positive	Negative	Positive	Negative	Positive
No Certification	1,303	157	1,262	173	1,345	155	1,293	167
BRC	124	74	122	103	125	97	140	72
SQF	244	28	274	32	257	35	347	30
FSSC	17	2	16	3	12	2	13	0
Total	1,688	261	1,674	311	1,749	289	1,793	269

Note: "Negative" indicates that the establishment has no positive results for the pathogen in the year; "positive" indicates that the establishment has at least one positive result for the pathogen in the year.

Table 3.10 The Number of Establishments by Certification Status, *Campylobacter* Test Results and Year

Test Results	2015		2016		2017		2018	
	Negative	Positive	Negative	Positive	Negative	Positive	Negative	Positive
No Certification	87	86	87	90	123	60	145	68
BRC	58	38	53	54	72	36	55	38
SQF	26	12	19	20	32	14	38	16
FSSC	2	0	1	1	3	0	1	0
Total	173	136	160	165	230	110	239	361

Note: "Negative" indicates that the establishment has no positive results for the pathogen in the year; "positive" indicates that the establishment has at least one positive result for the pathogen in the year.

Table 3.11The Number of Establishments by Certification Status, *E. coli* Test Results and Year

Test Results	2015		2016		2017		2018	
	Negative	Positive	Negative	Positive	Negative	Positive	Negative	Positive
No Certification	790	4	774	4	805	9	809	4
BRC	49	0	55	1	59	1	60	0
SQF	57	0	59	1	55	0	60	0
FSSC	8	0	7	0	3	0	4	0
Total	904	0	895	6	922	10	933	4

Note: "Negative" indicates that the establishment has no positive results for the pathogen in the year; "positive" indicates that the establishment has at least one positive result for the pathogen in the year.

Table 3.12 The Number of Establishments by Certification Status, Non-O157 STECs Test Results and Year

Test Results	2015		2016		2017		2018	
	Negative	Positive	Negative	Positive	Negative	Positive	Negative	Positive
No Certification	243	9	234	14	268	13	291	3
BRC	16	2	20	1	21	0	21	1
SQF	3	0	4	0	2	0	6	0
FSSC	2	0	2	0	1	0	2	0
Total	264	11	260	15	292	13	320	4

Note: “Negative” indicates that the establishment has no positive results for the pathogen in the year; “positive” indicates that the establishment has at least one positive result for the pathogen in the year.

Table 3.13 The Number of Establishments by Certification Status, *Listeria* Test Results and Year

Test Results	2015		2016		2017		2018	
	Negative	Positive	Negative	Positive	Negative	Positive	Negative	Positive
No Certification	909	24	923	16	972	12	900	14
BRC	95	1	110	0	112	1	113	1
SQF	200	2	260	1	240	4	327	2
FSSC	11	0	13	0	11	0	9	0
Total	11215	27	11306	17	11335	17	11349	17

Note: "Negative" indicates that the establishment has no positive results for the pathogen in the year; "positive" indicates that the establishment has at least one positive result for the pathogen in the year.

Table 3.14 Regressions Results for *Salmonella*

Variables	Pooled	Random	Fixed	Firth
BRC	-0.08	0.13	0.31***	-0.08*
	(0.14)	(0.15)	(0.12)	(0.05)
SQF	-0.04	-0.17	-0.12	-0.04
	(0.12)	(0.15)	(0.15)	(0.06)
FSSC	-0.59*	-0.67	Omitted	-0.50
	(0.36)	(0.46)	Omitted	(0.44)
Lagged Enforcement	0.13	0.13	0.01	0.14
	(0.17)	(0.18)	(0.14)	(0.11)
Sales Volume	-0.03	0.05*	-0.04	-0.03***
	(0.03)	(0.02)	(0.05)	(0.01)
Meat	0.63***	-0.24		0.63***
	(0.15)	(0.21)		(0.05)
Poultry	0.03	0.33*		0.03
	(0.21)	(0.20)		(0.11)
Export	-0.14	-0.21*		-0.14***
	(0.12)	(0.13)		(0.05)
Import	Omitted	Omitted	Omitted	-0.82
				(1.45)
Egg	0.20	-0.32	Omitted	0.58
	(0.53)	(0.46)		(0.85)
Turkey	1.94***	1.76***	-0.08	1.94***
	(0.37)	(0.41)	(0.30)	(0.19)
Chicken	3.85***	2.94***	0.10	3.84***
	(0.24)	(0.33)	(0.15)	(0.12)
Beef	2.30***	2.24***	0.60***	2.29***
	(0.20)	(0.22)	(0.19)	(0.13)
Egg	Omitted	Omitted	Omitted	-2.45
				(1.65)
Constant	-7.31***	-7.26***		-6.75***
	(0.33)	(0.63)		(1.44)
State Control	Yes	Yes	Yes	Yes
Year Control	Yes	Yes	Yes	Yes
Month Control	Yes	Yes	Yes	Yes
Observations	61,464	61,464	34,443	64,679

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 3.15 Regression Results for *Campylobacter*

Variables	Pooled	Random	Fixed	Firth
BRC	-0.57***	-0.44**	-0.12	-0.57***
	(0.20)	(0.17)	(0.24)	(0.09)
SQF	-0.23	-0.31	-0.38	-0.23*
	(0.20)	(0.19)	(0.30)	(0.12)
FSSC	0.36	0.44	Omitted	0.70
	(0.54)	(0.63)		(0.90)
Lagged Enforcement Action	-0.49	-0.69*	-0.75**	-0.47*
	(0.32)	(0.35)	(0.32)	(0.27)
Sales Volume	-0.03	-0.01	0.04	-0.03*
	(0.04)	(0.04)	(0.08)	(0.02)
Meat	0.12	0.06	Omitted	0.12
	(0.20)	(0.19)		(0.09)
Export	0.07	-0.01	Omitted	0.07
	(0.23)	(0.22)		(0.11)
Turkey	-2.25***	-2.66***	-3.56***	-2.20***
	(0.37)	(0.39)	(1.01)	(0.29)
Constant	-2.69***	-3.201***		-2.68***
	(0.42)	(0.46)		(0.21)
State Control	Yes	Yes	Yes	Yes
Year Control	Yes	Yes	Yes	Yes
Month Control	Yes	Yes	Yes	Yes
Observations	29,188	29,188	22,954	29,704

Robust standard errors in parentheses

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 3.16 Regression Results for *E. coli*

Variables	Pooled	Random	Fixed	Firth
BRC	-0.80	-0.80	Omitted	-0.63
	(0.72)	(0.72)		(0.77)
SQF	-0.08	-0.08	Omitted	0.22
	(1.04)	(1.03)		(0.92)
Lagged Enforcement Action	-0.08	-0.08	0.28	0.18
	(1.10)	(1.10)	(1.29)	(0.90)
Sales Volume	-0.13	-0.13	1.51	-0.13
	(0.11)	(0.11)	(1.15)	(0.09)
Poultry	-0.54	-0.543		-0.51
	(0.46)	(0.46)		(0.48)
Export	0.92*	0.923*		0.87*
	(0.51)	(0.51)		(0.51)
Import				2.84
				(2.05)
Egg			Omitted	5.39**
				(2.23)
Constant	-5.37***	-5.367***		-6.52***
	(1.23)	(1.44)		(2.11)
State Control	Yes	Yes	Yes	Yes
Year Control	Yes	Yes	Yes	Yes
Month Control	Yes	Yes	Yes	Yes
Observations	12,249	12,249	1,087	29,308

Note: For fixed-effect model, BRC, SQF, and FSSC do not enter the regression. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 3.17 Regression Results for Non-O157 STECs

Variables	Pooled	Random	Fixed	Firth
BRC	-1.18	-1.18	-12.96	-1.02
	(0.85)	(0.85)	(1,38)	(0.79)
SQF	Omitted	Omitted	Omitted	-0.33
				(2.31)
FSSC	Omitted	Omitted	Omitted	-1.02
				(1.58)
Lag Enforcement Action	0.70	0.70	0.72	0.73
	(0.75)	(0.88)	(0.68)	(0.48)
Sales Volume	-0.11	-0.11	0.23	-0.10
	(0.11)	(0.11)	(0.55)	(0.09)
Poultry	-0.92**	-0.92		-0.84**
	(0.44)	(0.60)		(0.39)
Export	0.31	0.31		0.28
	(0.39)	(0.40)		(0.42)
Constant	-2.72*	-2.72		-2.28
	(1.48)	(1.82)		(1.62)
State Control	Yes	Yes	Yes	Yes
Year Control	Yes	Yes	Yes	Yes
Month Control	Yes	Yes	Yes	Yes
Observations	3,613	3,613	873	6,446

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 3.18 Regression Results for *Listeria*

Variables	Pooled	Random	Fixed	Firth
BRC	-1.01	-0.98		-0.80
	(0.82)	(0.82)		(0.68)
SQF	-1.17*	-1.32**	-15.67	-1.07**
	(0.63)	(0.58)	(1.23)	(0.47)
FSSC	Omitted	Omitted	Omitted	-0.59
				(1.45)
Lag Enforcement Action	1.08**	0.78	-0.47	1.15**
	(0.54)	(0.56)	(0.71)	(0.51)
Sales Volume	-0.02	-0.01	-0.11	-0.02
	(0.08)	(0.08)	(0.42)	(0.06)
Meat	1.36	1.36		-0.05
	(0.96)	(0.97)		(3.28)
Export	-0.14	-0.19		-0.09
	(0.51)	(0.49)		(0.43)
Ready-to-Eat	-1.46	-1.62		-0.38
	(1.24)	(1.26)		(3.65)
Constant	-5.03***	-5.81***		-4.10**
	(1.70)	(1.70)		(1.87)
Observations	16,198	16,198	873	24,228

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 3.19 Average Marginal Effects for Certification Status

Average Marginal Effects	*Salmonella*	*Campylobacter*	*E. coli*	non-O157 STECs	*Listeria*
BRC	-0.003*	-0.02***	-0.001	-0.01	-0.003
	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)
SQF	-0.001	-0.01*	0.000	-0.003	-0.004**
	(0.00)	(0.00)	(0.00)	(0.02)	(0.00)
FSSC	-0.02	0.02	0.002	-0.01	-0.002
	(0.02)	(0.03)	(0.00)	(0.02)	(0.01)

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 3.20 Average Marginal Effects for Lagged Certification Status

Average Marginal Effects	*Salmonella*	*Campylobacter*	*E. coli*	non-O157 STECs	*Listeria*
Lagged BRC	-0.01***	-0.02***	-0.001	-0.01	-0.002
	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)
Lagged SQF	-0.002	-0.01*	0.000	-0.001	-0.002**
	(0.00)	(0.00)	(0.00)	(0.02)	(0.00)
Lagged FSSC	-0.03	0.02	0.002	-0.01	-0.002
	(0.02)	(0.03)	(0.00)	(0.02)	(0.01)

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

CHAPTER 4. RELATIONSHIP-SPECIFIC LEARNING IN THE PRIVATE FOOD SAFETY CERTIFICATION MARKET

4.1 Introduction

In this study, we investigate the relationship-specific learning-by-doing in the private food safety certification market using the British Retail Consortium (BRC) certification as an example. We are interested in how the working experience between the pair of a manufacturer and its certification body affects the efficiency of the certification process. Learning-by-doing can be relationship-specific when productivity or efficiency improvements are associated with the accumulative experience specific to pairs of firms working together in a contract relationship (Kellogg, 2011). The intuition of relationship-specific learning-by-doing is that working together over time as a team may build skills, knowledge, and familiarity, creating relationship-specific human capital that is difficult to fully transfer to a different team. The explanations for relationship-specific learning can be broken down into coordination and team "psychological safety" (Huckman et al., 2009). Familiarity may improve the ability to act in a coordinated manner when the work requires the joint effort of a team (Moreland et al., 2002). Also, familiarity could result in "psychological safety" and thus impact learning and performance (Edmondson, 1999). Therefore, relationship-specific learning-by-doing is possible to achieve, especially for individuals or firms who provide services to multiple firms.

McCabe (1996) finds that the productivity with short-term relationships is less than the ones with long-term relationships between nuclear power plants and their contractors. Kellogg (2011) finds productivity increases with the joint experience between the oil production company and its drilling contractor. These two studies highlight the importance of relationship-specific learning between organizations or firms. Another strand of literature takes advantage of workers moving from one organization to another and examines their performances in the context of team-specific experience. Huckman et al. (2009) find the performance of software firms depends on team-specific experience rather than individual member experience. Narayan and Kadiyali (2016) find that relationship-specific learning exists in the movie industry, and it positively affects revenue with repeated interactions between producers and other team members. More evidence of relationship-specific learning is found in the hospitals. Huckman and Pisano (2006) find evidence that the performance of cardiac surgeons, many of whom often perform operations at multiple hospitals, improves significantly with their hospital-specific experience instead of the overall experience at other hospitals. KC and Staats (2011) demonstrate that the non-firm-specific experience of cardiothoracic surgeons reduces the learning rate. Bartel et al. (2014) find that nurses' team-specific experience significantly improves patient outcomes. Averinos and Gokpinar (2016) observe that the productivity of the team increases with the familiarity of the team in a private hospital in Europe. Chen (2016) similarly finds working experience as a team between the doctors who performs the procedure and the doctors who provide care to the patient reduces patient mortality rates. In sum, studies in the literature find that team productivity increases with team-specific experience because of building up team familiarity.

Although the literature indicates the existence of relationship-specific learning in various settings, such as the drilling industry, hospitals, software firms, and the movie industry, it remains unclear and unexplored about the precise role of relationship-specific learning in the certification market. Building upon prior work, particularly the work by

Kellogg (2011), we aim to examine the effect of relationship-specific learning in the context of the private food safety certification market.

There are seven key stakeholders in the private food safety certification market as described in Chapter One: private food safety standards, government, accreditation bodies, certification bodies, retailers, consumers, and producers/manufacturers. Out of the seven stakeholders, manufacturers and certifications are two relevant ones in this study. To obtain a private certification, the manufacturer needs to find a certification body that offers the private standard they would like to certify with. Then the certification body sends an auditor to the manufacturer to assess if the manufacturer's food safety system, for example, the Hazard Analysis and Critical Control Plan (HACCP), meets the standards. The manufacturer is responsible for the fees generated during the assessment. Relationship-specific learning is possible with repeated interactions in the certification process. The certification body may become familiar with the manufacturer's basic information and its food safety system, or the manufacturer's employees may improve their knowledge of the certification body's requirements. In other words, the manufacturer and certification body may develop a working relationship, which allows them to collaborate more effectively and leads to cost reduction for manufacturers.

It is essential to understand the role of relationship-specific learning between certification bodies and manufacturers because such learning may have potential implications for cost reduction strategies for manufacturers. Therefore, we examine whether certification bodies and manufacturers work as pairs can develop the relationship-specific learning that eventually decreases the cost of certification using the British Retail Consortium (BRC) standard as an example. We discover that the time for obtaining certification reduces with the increase of manufacturers' overall experience with BRC certification. More importantly, we find that the time for obtaining certification reduces with the increase of the relationship-specific experience between manufacturers and certification bodies, which demonstrates the existence of efficiency gains from relationship-specific learning-by-doing in the BRC certification market.

This paper contributes to two strands of literature. First, this study contributes to the literature on relationship-specific learning-by-doing in the general context. Particularly, it adds to the underexplored literature that examines the learning process between firms or organizations. Second, this study contributes to the growing body of research on the private food safety certification market, in specific, on the interaction between manufacturers and certification bodies. Prior work has examined the factors that affect a manufacturer's choice of certification body (Bar and Zheng, 2018) and determinants of audit grades, using BRC as an example (Zheng and Bar, 2021). This study adds to the current literature in the market of private food safety certification and sheds light on the efficiency gains from working with the same certification body.

The remainder of this study proceeds as follows. Section 4.2 introduces the background of the private food safety certification. Section 4.3 describes the data and primary variables used in this study. Section 4.4 discusses the methodology and results. Section 4.5 discusses the implications of my findings.

4.2 Background of the Private Food Safety Certification

Founded in 1996, the BRC standard is now an internationally recognized standard and one of the Global Food Safety Initiative (GFSI) recognized certification schemes. It provides food safety certification for food manufacturers[11] to build an effective food safety management system. The scope of BRC certification does not only limit to food safety but also covers certification areas such as gluten-free certification and plant-based meat certification. So far, BRC food safety certification has been adopted by 20,000 manufacturers in 130 countries[12]. BRC food safety standard covers a variety of products, such as meat, poultry, fruits, vegetables, bakery, and snacks. Generally, the certified products are classified into 18 categories, as shown in table 4.1.

To certify with BRC standard, a manufacturer must contact a certification body, file a company profile application, and ask for a quote for the costs. Once the manufacturer accepts the quote, an auditor from this certification body is then assigned to conduct the audit. The auditor's responsibility is to assess the food safety system and report non-compliances (identified as minor or major) against the BRC standard. After the auditing process, the manufacturer is given a period of time to do corrective actions according to the non-compliance records before receiving the certification. Audit grades are based on non-compliances during the on-site audit. The certification status expires typically in 12 months (for grade A or grade B) or six months (grade C), depending on the audit grade. Upon the expiration of the certification status, manufacturers can decide whether to recertify with the same certification body or change to certify with a different one.

This study is motivated by the objective of manufacturers to minimize the time needed to certify, as motivated by their objectives to minimize their certification costs. It is important for the manufacturers because the certification cost is not trivial, especially for

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[11] BRC only covers manufacturing/processing activities but does not cover pre-farmgate activities. We use the term "manufacturers" throughout this study to distinguish BRC from pre-farmgate standards.
[12] Data source is found at: https://www.brcgs.com/our-standards/food-safety/. Last access on May 17, 2022.

small manufacturers (in general, the initiation certification costs exceed $5,000 plus additional registration fees, etc.). Even with certification, a manufacturer needs to go through a recertification process every year or every six months. The most significant component of certification cost is the labor fee paid to the auditor for the time spent on-site. Therefore, it is of vital importance to examine the learning from certifying and help manufacturers, especially small manufacturers, to reduce the certification costs when they seek certifications.

The pricing scheme varies by standards, but some common fees occur in the audit process. The typical fees include (1) the on-site audit fee, which usually depends on the size and HACCP of the manufacturers; (2) the report writing fee; (3) the administrative fee, which represents the costs associated with the technical review, report uploading, generating the certificate, etc.; (4) the travel fee, which captures the cost of the auditor's airfare, lodging, etc.; (5) the certification fee, which is a mandatory fee to receive the certification[13]; (6) the cost associated with corrective action, which is a cost generated to correct non-compliances detected by auditors.

In practice, there is little room to reduce administrative fee, report writing fee and registrations fee because they are flat-rate fees set by the standard. Manufacturers may reduce costs in three ways. First, manufacturers can mitigate travel-related expenses by choosing a certification body closer to the manufacturer. Bar and Zheng (2018) find evidence that manufacturers are more likely to choose geographically closer certification bodies. Second, manufacturers may achieve cost savings by reducing on-site audit time.

[13] The cost of a GFSI audit source: Found at: https://safefoodalliance.com/gfsi/what-to-look-for-in-the-price-of-a-gfsi-audit/#:~:text=BRCGS%3A,and%20%247500%2C%20excluding%20travel%20expenses. (last accessed May 12,2022).

Third, manufacturers could reduce corrective action costs by improving the food safety system. This analysis mainly focuses on whether working with the same certification body creates a relationship-specific human capital and influences the on-site audit time. Working in pairs between manufacturers and certification bodies may be a potential way to gain knowledge and familiarity for better collaboration with each other. In addition, we provide insights on whether audit grades play a role in reducing the time to successfully certify. Using our dataset from BRC, we can identify the relationships between manufacturers and certifications. Therefore, we can investigate whether there is relationship-specific learning-by-doing in the certification process (efficiency gains in the certification process). In another work, we can examine learning-by-doing specific not just to individual manufacturers but to pairs of manufacturers and certification bodies work together.

4.3 Data and Primary Variables

We hypothesize that a long-term relationship between a certification body and a manufacturer induces relationship-specific learning-by-doing and therefore reduces the time needed to conduct and finish the certification process, which results in efficiency gain.

We utilize data obtained from the BRC standard program. This dataset includes 11,501 observations, covering 2,157 manufacturers that adopt the BRC certifications from January 2015 to January 2022. We only include manufacturers that we can observe the first time they certify with the BRC standard, which means that all the manufacturers included in our study start certifying with BRC after the year 2015. Also, we drop the manufacturers that only appear once in the dataset because tracking learning requires at least two periods. In the dataset, each observation identifies the manufacturer and the certification body that the manufacturer chooses. One unique feature of this proprietary BRC data is that the data includes starting date and ending date of the certification process. Therefore, the length of the certification process of each manufacturer is known to us. We use this to define the dependent variable.

Dependent Variable: the dependent variable is the number of days to certify, taken as the difference between the audit starting date and the certification issuing date. This variable reflects the time a certification body takes to conduct the audit, write a report, and the time for a manufacturer to take corrective action upon the report.

$$Certification\ Time_{i,j,t} = Certification\ Issue\ Date_{i,j,t} - Audit\ Start\ Date_{i,j,t} \qquad (1)$$

The primary independent variables in our study include *Pair Experience*, *Experience with Others*, *Certification Body Experience*, and *Audit Grade*.

Pair Experience: work experience in a pair for manufacturer i and certification body j in year t is measured as the cumulative number of years that the pair has worked together. Specifically,

$$Pair\ Experience_{i,j,t} = \sum_{t=1}^{T} N_{i,j,t} \qquad (2)$$

Experience with Others: manufacturer's certification experience with certification bodies other than its current certification body. We need a variable that captures the manufacturers' overall experience with BRC certification. However, it will be highly correlated with *Pair Experience*. To avoid such collinearity, we construct *Experience with Others*, where g denotes the current certification body in year t. This variable is calculated as below:

$$Experience\ with\ Others_{i,j\neq g,T} = \sum_{t=1}^{T} N_{i,j\neq g,t} \qquad (3)$$

To demonstrate how we construct the variables *Pair Experience* and *Experience with Others*, we give two examples in table 4.2. Manufacturer one certifies with the same certification body from 2015 to 2022, while manufacturer two changes the certification body in 2019. The variable *Pair Experience* for manufacturer one in 2015 is one and increases as time moves on, whereas *Experience with Others* is zero from 2015 to 2022. For manufacturer two, the variable *Pair Experience* is one, two, three, and four for 2015, 2016, 2017, and 2018, respectively. It restarts at one in 2019 when the manufacturer switches to a new certification body. The variable *Experience with Others* is zero from 2015 to 2018; it becomes four in 2019 since manufacturer two has had four-year experiences working with its initial certification body.

Certification Body Experience: we measure it as the number of manufacturers that the certification body j audited in the year $(t-1)$. In the literature, researchers demonstrate that experience effects decay with time (Argote et al., 1990; Benkard, 2000; Thompson, 2007), indicating experiences in the distant past may not be relevant for current performance. Studies have used recent work experience as a measurement instead of total work experience (Chen, 2021; Kellogg, 2011). Therefore, we use the experience within the past year rather than the total cumulative experiences.

$$Certification\ Body\ Experience_{j,t-1} = \sum_{i=1}^{I} N_{i,t-1} \qquad (4)$$

Audit Grade: manufacturers receive an audit grade if passing the audit, denoting as $Grade_{i,t}$. Passing grades in our analysis are A, B, or C. The grades depend on the non-compliances against standard requirements that the auditors detected (Zheng and Bar, 2021). Manufacturers need to take corrective actions to fix the non-compliances to receive the final certification. For example, manufacturers receiving grade A indicates they have less than ten minor non-compliances, while manufacturers receiving grade C have at least one major non-compliances and dozens of minor non-compliances.

Overall, there are three types of factors that can affect the time for auditing. These are (1) effects that are specific to manufacturer-certification body combinations, represented by the variable *Pair Experience*; (2) certification body effects that are independent of the manufacturers, captured by the variables *Experience with Others*; (3) manufacturer-level characteristics that are independent of the certification body, represented by *Experience with Others*. These are the primary variables in this analysis.

Table 4.3 exhibits the summary statistics of our primary variables and the dependent variable. The mean of the variable *Pair Experience* is 2.67, which indicates that, on average, manufacturers stay with the same certification for 2.67 years. Since slightly more than half of the manufacturers do not change certification bodies, meaning the number of years that the manufacturers and certification bodies working together is zero, thus, the mean of the variable *Experience with Others* is as low as 0.82. Certification bodies' audited manufacturers are around 204. The standard deviation for this variable shows that there is a large variance in certifying activities across these certification bodies. Table 4.4 lists the number of audited manufacturers by the certification body code[14] and year. We can see that a few certification bodies dominate the market. For example, certification body one, representing AIB international, certifies around 200-300 manufacturers each year. In contrast, certification body two, representing BSI Group, has no certified manufacturers from 2015 to 2018. In fact, there are more than ten certification bodies that have zero certified sites each year. Given the large heterogeneity of the certification bodies, it entails

[14] Certification body name is attached in the appendix.

the importance of including controls at the certification body level. Audit grade is reconstructed for the purpose of summary statistics: grade A is 4; grade B is 3; grade C is 2. On average, the audit grade is 3.89, inclining more to grade A. To look at the grade distribution further, we list the number of manufacturers by grade and year in table 4.5. More than 87% of manufacturers receive grade A, and only less than 1% of them receive grade C. In terms of the dependent variable, the average certification time is 41 days. The days vary significantly between grades. We show the average certification days by audit grade in table 4.6. The *p*-value is the value that compares the grade with the other two grades. For example, the *p*-value for "Grade A" means that the average certification time for manufacturers receiving grade A is significantly different from those receiving grade B and grade C. Additionally, we categorize certification time into seven ranges and calculate the number of manufacturers for each range. From table 4.7, we can see that less than 1% of manufacturers take one to 13 days to complete the certification process; the majority of the manufacturers take 24 to 49 days; less than 1% of manufacturers take more than one year to obtain a certification. The bottom row of table 4.4 represents the number of manufacturers certifying with BRC. Overall, the number keeps increasing, from 1,327 in 2015 to 1,790 in 2021[15].

Out of the 2,157 manufacturers included in our dataset, 1,009 change certification bodies at least once during the observed period. Table 4.8 provides simple comparisons between "switchers" and "nonswitchers". We consider a manufacturer to be a switcher if it changes the certification body at least once during the observed period. "Nonswitchers" are those that stay with one certification body the whole time during the study window.

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[15] We only have January data for 2022, that's why the number for 2022 is much lower.

Based on this criterion, roughly 47% of the manufacturers in the sample are “switchers”. We observe differences between them in the statistics summary in table 4.8. For “switchers”, the average year staying with one certification body is lower, the average year of experience with other certification bodies is higher, the grade is lower, and the average certification time is longer than “nonswitchers”. The *p*-values from the last column indicate that the “switchers” and “nonswithers” are significantly different at 1% level regarding the variables *Pair Experience*, *Experience with Others*, *Certification Body Experience*, *Grade*, and *Certification Time*.

4.4 Methodology and Results

We build on the previous literature on learning-by-doing. In particular, Kellogg (2011) examines learning by doing in the drilling industry. He finds that the productivity of an oil production company and its drilling contractor increases with their experience working together. We will apply a similar methodology to our food safety certification data but use the certification length to measure efficiency instead.

Specifically, our empirical specification takes the following form:

$$\log(Certification\ Time_{i,j,t}) = \alpha_{i,j,t} + \beta_1 \log(Pair\ Experience_{i,j,t}) + \beta_2 \widetilde{Experience\ with\ Others}_{i,j\neq g,t} + \beta_3 \log(Certification\ Body\ Experience_{j,t-1}) + \beta_4 A_{i,t} + \beta_5 B_{i,t} + \beta_6 C_{i,t} + \theta_i + \gamma_j + \varepsilon_{i,j,t} \quad (5)$$

Where i, j, and t denote manufacturer, certification body, and year, respectively; $Certification\ Time_{i,j,t}$, the dependent variable is the certification process length for manufacturer i working with the certification body j in year t; $Pair\ Experience_{i,j,t}$ is the cumulative years of manufacturer i working with certification body j in year t;

$Experience\ with\ Others_{i,j\neq g,t}$ is the cumulative years of manufacturer i working with other certification bodies $j \neq g$ in year t; g represents the certification body in year t; $Certification\ Body\ Experience_{j,t-1}$ is the number of certified sites under the certification body j in year $t-1$; $Grade\ A_{i,t}$, $Grade\ B_{i,t}$, and $Grade\ C_{i,t}$ are dummy variables denoting manufacturer i's audit grade in year t; $\theta_i + \gamma_j$ are fixed effects for unobservable factors regarding the manufacturers and certification bodies, respectively; and $\varepsilon_{i,j,t}$ is the error term. We expect the coefficient for $Pair\ Experience_{i,j,t}$, since we expect that there exists relationship-specific learning by doing between manufacturers and certification bodies that

We take log transformation for $Certification\ Time_{i,j,t}$, $Pair\ Experience_{i,j,t}$, and $Certification\ Body\ Experience_{i,t-1}$. The variable $Experience\ with\ Others_{i,j\neq g,t}$ takes the inverse hyperbolic sine (IHS) transformation as follows:

$$Experience\ \widetilde{with}\ Others_{i,j\neq g,t} = \log\left(Experience\ with\ Others_{i,j\neq g,t} + \sqrt{\left(Experience\ with\ Others_{i,j\neq g,t}\right)^2 + 1}\right) \quad (6)$$

The IHS transformation is applied to transform variables that include zero or negative values, and it allows a similar interpretation of the regression results as the log transformation (Aihounton and Henningsen, 2019).

The key variable of interest is *Pair Experience*, which measures the number of years manufacturer *i* and certification body *j* have worked together as a pair. Therefore, the coefficient β_1 captures how a pair of a manufacturer and a certification body working together could affect the time it takes to finish the certification process. The time to complete certification in the BRC data varies significantly, ranging from several days to more than half a year (or even two years). Such heterogeneity provides an essential source of variation for us to exploit in the econometric model. Specifically, we expect that β is positive. A positive β indicates learning by doing effect; that is, more years working together will speed up the certification process.

The empirical setting of our study allows us to separate the impact of relationship-specific learning from that of manufacturer-specific or certification body-specific learning. We conduct the regressions with a full sample, which is our main analysis. Additionally, we run the regressions with a sub-sample, where we drop the observations that are at the top 1% (less than 14 days) and bottom 1% (more than 353 days) of the certification time to reduce the effect of these extreme values.

The regression results of our main analysis are presented in table 4.9. All standard errors are robust standard errors. We gradually add variables and controls to observe the changes. The regression one only includes one variable, *Pair Experience*; the regression two adds audit grades; the regression three adds *Experience with Others* and *Certification Body Experience* in addition to these in regression two; the regression four includes all primary variables and manufacturer-level fixed effect; the regression five includes all primary variables and certification body-level fixed effects; the regression six has all primary variables, manufacturer-level, and certification body-level fixed effects.

The coefficient for *Pair Experience* starts to change as we add in the variables *Experience with Others* and *Certification Body Experience*. The coefficient for *Pair Experience* is -0.06 and significant at 1% level for regression one and regression two, whereas it is -0.01 and insignificant for regression three. When we add manufacturer-level controls and certification body-level controls, the coefficients change more with the inclusion of certification body-level controls than manufacturer-level controls. The changes in regressions four, five, and six imply that identification of relationship-specific learning will fail if we don't control for manufacturer-level and certification body-level characteristics.

Regression six is with all primary variables and both controls; we will focus on this column from this point. The coefficient of *Pair Experience* is -0.04 and significant at 1% level. The point estimate implies that maintaining a stable relationship with the same certification bodies for another year will help manufacturers reduce the time to complete the certification by one day, keeping everything else constant. Manufacturers learn from experiences with other certification bodies as well. The coefficient of *Experience with Others* is -0.08 and is significant at 1% level, which indicates that manufacturers' overall experience with other certification bodies helps reduce the time to finish the certification process. The point estimate, -0.08, translates to a one-day reduction in certification time. The coefficient of *Certification Body Experience* is 0.03 and significant at 1% level. It tells us that as the number of certified sites for the certification bodies increases, it takes a longer time for certification bodies to process certification because of more workload.

Table 4.10 presents the regression results for the sub-sample where we drop observations with extreme values of certification time. The structure of this table is the same as table 4.9. Results are similar to the ones from table 4.9 except for the variable *Certification Body Experience*. After taking out the extreme values of certification time, the coefficient of *Certification Body Experience* is no longer significant. Similar and consistent results are generated for relationship-specific experience, manufacturer-specific experience, and certification body-specific experience.

This section has presented two sets of results. Both sets of results consistently indicate that an additional year working with the same certification bodies reduces the time to complete the certification process by one year; the results from experiences with other certification bodies and audit grade suggest that manufacturers' learning that independent of certification bodies is important as well. These findings pinpoint the prominent role of relationship-specific learning in driving the efficiency of certification processing time as well as the role of manufacturers' learning from certifying with BRC.

4.5 Conclusions

The impact of relationship-specific learning on the efficiency of certification processing is unclear in the context of the private food safety certification market. The panel data from BRC allows us to explore not only the effect of manufacturing-specific learning but also to single out the potential impact of relationship-specific learning between manufacturers and certification bodies. We examine 2,157 BRC-certified manufacturers and their certification body pairs from January 2015 through January 2022. We find that manufacturers' overall experience with BRC certification improves efficiency to certify. More importantly, we find that work-in-pair experience between the manufacturers and the certification bodies significantly reduces the time to complete the certification process, which sheds light on how relationship-specific learning affects efficiency.

Our study has important implications for manufacturers. Though manufacturer-specific learning is significant in reducing certification time to achieve cost reduction, relationship-specific learning between manufacturers and certification bodies is as important. Manufacturers and certification bodies gain familiarity and human capital through repeated corporations that improve the certification efficiency. Given the $200 per hour industry rate and eight-hour intensity working intensity per day, a one-day reduction in certification time equals around 1,600 dollars saved in certification costs, according to a back-on-the-envelope calculation. The results of this study will help manufacturers to make decisions about recertifying. Furthermore, since many certification bodies carry multiple standards, we believe that this study using the BRC standard as an example could be generalized to other private food safety standards.

This study is just a small first step in exploring the relationship-specific learning-by-doing in the private certification market. Limited by data availability, we are unable to split the certification time into on-site audit time, reports-writing time, and time for corrective actions. In the future, it is useful to collect more detailed data on certification time so that we can pinpoint which stage of the process is affected and thus better help the manufacturers make cost reduction strategies.

Table 4.1 BRC Certified Food Categories

Code	Food Category
1	Raw red meat
2	Raw poultry
3	Raw prepared products (meat and vegetarian)
4	Raw fish products and preparations
5	Fruits, vegetables and nuts
6	Prepared fruit, vegetables, and nuts
7	Dairy, liquid egg
8	Cooked meat/fish products
9	Raw cured/or fermented meat and fish
10	Ready meals and sandwiches; ready to eat desserts
11	Low/high acid in cans/glasses
12	Beverages
13	Alcoholic drinks and fermented/brewed products
14	Bakery
15	Dried foods and ingredients
16	Confectionery
17	Cereals and snacks
18	Oils and fats

Table 4.2 Two Examples of the Construction of the Variables *Pair Experience* and *Experience with Others*

Year	Manufacturer One		Manufacturer Two	
	Pair Experience	Experience with Others	Pair Experience	Experience with Others
2015	1	0	1	0
2016	2	0	2	0
2017	3	0	3	0
2018	4	0	4	0
2019	5	0	1	4
2020	6	0	2	4
2021	7	0	3	4
2022	8	0	4	4

Note: *Pair Experience* represents the number of years that the pair of a manufacturer and a certification body work together; *Experience with Others* represents the number of years that a manufacturer work with a certification body other than its current certification body. In these two examples, manufacturer one stays with the same certification body from 2015 to 2018; manufacturer changes the certification body in 2019.

Table 4.3 Summary Statistics for Primary Variables and the Dependent Variable

Variable	Mean	Standard Deviation
Pair Experience	2.67	1.70
Experience with Others	0.82	1.38
Certification Body Experience	203.90	112.33
Audit Grade	3.89	0.37
Certification Time	41.06	39.99

Note: *Pair Experience* represents the years that the manufacturers work with the same certification body. *Experience with Others* represents the years that the manufacturers work with certification bodies other than their current certification bodies. *Certification Body Experience* represents the number of certified manufacturers for certification bodies. *Certification Time* measures the length of processing time to obtain a certification.

Table 4.4 The Number of Certified Manufacturers by Certification Body and Year

Certification	2015	2016	2017	2018	2019	2020	2021	2022	Total
1	273	325	338	339	348	288	360	11	2,282
2	0	0	0	0	1	1	0	0	2
3	3	0	0	0	0	0	0	0	3
4	1	7	10	0	0	0	0	0	18
5	0	0	0	0	2	6	9	2	19
6	248	307	279	0	0	0	0	0	834
7	8	0	0	0	0	0	0	0	8
8	35	40	61	60	64	45	63	1	369
9	19	23	20	25	27	24	25	0	163
10	0	0	0	0	0	1	3	0	4
11	0	8	14	28	25	5	11	1	92
12	1	15	0	0	0	0	0	0	16
13	147	170	206	222	220	217	275	17	1,474
14	0	3	40	292	260	255	257	11	1,118
15	3	7	10	8	5	0	0	0	33
16	0	40	38	30	0	0	0	0	108
17	14	0	0	0	0	0	0	0	14
18	17	0	0	12	26	31	35	3	124
19	0	1	1	1	1	0	0	0	4
20	0	1	1	0	0	0	0	0	2
21	1	81	82	86	89	84	91	5	519
22	0	0	2	2	2	2	0	0	8
23	273	318	274	297	299	236	238	10	1,945
24	14	10	10	6	7	5	8	0	60
25	0	0	0	2	2	0	0	0	4
26	22	26	19	16	0	0	0	0	83
27	81	116	108	76	0	0	0	0	381
28	44	54	37	59	129	109	124	5	561
29	11	0	0	0	0	0	5	0	16
30	0	0	0	1	0	1	1	0	3
31	43	57	71	63	65	49	66	6	420
32	1	16	20	26	25	39	36	3	166
33	60	0	0	0	0	0	0	0	60
34	2	6	14	37	45	28	33	7	172
35	6	20	19	5	0	0	0	0	50
36	0	8	0	0	0	0	0	0	8
37	0	5	39	39	32	72	145	13	345
38	0	0	0	0	2	5	5	1	13
Total	1,327	1,664	1,713	1,732	1,676	1,503	1,790	96	11,501

Note: The names of certification body and their corresponding code are attached in the appendix.

Table 4.5 The Number of Manufacturers by Audit Grade and Year

Grade	2015	2016	2017	2018	2019	2020	2021	2022	Total
A	1,159	1,498	1,565	1,579	1,502	1,391	1,689	87	10,470
B	155	152	140	142	149	100	95	7	940
C	13	14	8	11	25	12	6	2	91
Total	1,327	1,664	1,713	1,732	1,676	1,503	1,790	96	11,501

Table 4.6 Summary Statistics of the Certification Time by Audit Grade

Grade		Certification Time
	Mean	40.85
Grade A	Standard Deviation	40.07
	p-value	0.07
	Mean	42.92
Grade B	Standard Deviation	39.02
	p-value	0.12
	Mean	45.80
Grade C	Standard Deviation	41.08
	p-value	0.27

Note: The *p*-value for each grade compare the significance of the grade and other grades. For example, the p-value for grade A compares the certification time between manufacturers with grade A and with other grades (B and C).

Table 4.7 The Number of Manufacturers by the Range of Certification Time

Certification Time Range	Number of Manufacturers	Cumulative Percentage (%)
1-13	111	0.97
14-23	1,027	9.89
24-30	2,161	28.68
31-38	3,704	60.89
38-49	3,374	90.23
50-353	1,009	99.00
354-604	115	100.00

Table 4.8 Summary Statistics of Primary Variables for “Switchers” and “Nonswitchers”

	Switchers		Nonswitchers		
	Mean	Standard Deviation	Mean	Standard Deviation	p-value
Pair Experience	2.05	1.22	3.33	1.87	0.00
Experience with Others	1.61	1.58	0.00	0.00	0.00
Certification Body Experience	173.24	111.29	235.89	104.20	0.00
Grade	3.92	0.30	3.88	0.34	0.00
Certification Time	44.03	47.65	37.97	29.67	0.00

Note: *Pair Experience* represents the years that the manufacturers work with the same certification body. *Experience with Others* represents the years that the manufacturers work with certification bodies other than their current certification bodies. *Certification Body Experience* represents the number of certified manufacturers for certification bodies. *Certification Time* measures the length of processing time to obtain a certification.

Table 4.9 Regression Results for the Full Sample

Variables	1	2	3	4	5	6
$\log(\text{Pair Experience}_{i,j,t})$	-0.06***	-0.06***	-0.01	-0.02*	-0.04***	-0.04***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
$\text{Experience}\ \widetilde{\text{with}}\ \text{Others}_{i,j\neq g,t}$			0.02	-0.02	-0.03*	-0.08**
			(0.02)	(0.02)	(0.02)	(0.03)
$\log(\text{Certification Body Experience}_{j,t-1})$			-0.06***	-0.00	0.02**	0.03***
			(0.00)	(0.01)	(0.01)	(0.01)
$\text{Grade A}_{i,t}$		-0.14***	-0.14***	-0.08	-0.13***	-0.10*
		(0.04)	(0.04)	(0.05)	(0.04)	(0.05)
$\text{Grade B}_{i,t}$		-0.07	-0.08*	-0.04	-0.06	-0.04
		(0.04)	(0.04)	(0.05)	(0.04)	(0.05)
Constant	3.63***	3.76***	3.99***	3.58***	3.66***	3.46***
	(0.01)	(0.04)	(0.05)	(0.07)	(0.05)	(0.07)
Manufacturer Control	No	No	No	Yes	No	Yes
Certification Body Control	No	No	No	No	Yes	Yes
Observations	10,066	10,066	10,066	10,066	10,066	10,066
R-squared	0.01	0.01	0.03	0.33	0.11	0.35

Note: The variable *Experience with Others* takes the inverse hyperbolic sine transformation because of zero values. Regression 1 only includes *Pair Experience*; Regression 2 adds audit grades; Regression 3 adds *Experience with Others* and *Certification Body Experience* in addition to Regression 2; Regression 4 includes all primary variables and manufacturer-level fixed effect; Regression 5 includes all primary variables and certification body-level fixed effects; Regression 6 has all primary variables, manufacturer-level, and certification body-level fixed effects. All standard errors are robust and clustered at manufacturer level. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 4.10 Regression Results for Sub-Sample

Variables	1	2	3	4	5	6
$\log(\text{Pair Experience}_{i,j,t})$	-0.05***	-0.05***	-0.00	-0.02**	-0.03***	-0.03***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
$\widetilde{\text{Experience with Others}}_{i,j\neq g,t}$			-0.02	-0.05***	-0.02*	-0.07***
			(0.01)	(0.02)	(0.01)	(0.03)
$\log(\text{Certification Body Experience}_{j,t-1})$			-0.06***	-0.02***	-0.01	-0.01
			(0.00)	(0.01)	(0.01)	(0.01)
$\text{Grade A}_{i,t}$		-0.12***	-0.12***	-0.09**	-0.11***	-0.10**
		(0.03)	(0.03)	(0.04)	(0.03)	(0.04)
$\text{Grade B}_{i,t}$		-0.06*	-0.06*	-0.04	-0.05*	-0.04
		(0.03)	(0.03)	(0.04)	(0.03)	(0.04)
Constant	3.61***	3.72***	3.99***	3.71***	3.76***	3.63***
	(0.01)	(0.03)	(0.03)	(0.05)	(0.04)	(0.06)
Manufacturer Control	No	No	No	Yes	No	Yes
Certification Body Control	No	No	No	No	Yes	Yes
Observations	9,857	9,857	9,857	9,857	9,857	9,857
R-squared	0.01	0.01	0.06	0.40	0.18	0.42

Note: The variable *Experience with Others* takes the inverse hyperbolic sine transformation because of zero values. Regression 1 only includes *Pair Experience*; Regression 2 adds audit grades; Regression 3 adds *Experience with Others* and *Certification Body Experience* in addition to Regression 2; Regression 4 includes all primary variables and manufacturer-level fixed effect; Regression 5 includes all primary variables and certification body-level fixed effects; Regression 6 has all primary variables, manufacturer-level, and certification body-level fixed effects. All standard errors are robust and clustered at manufacturer level. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

APPENDIX 1. FULL ABBREVIATION LIST IN ALPHABETICAL ORDER

ANAB−−ANSI-ASQ National Accreditation Board

BRC—British Retail Consortium Food (BRC)

FDA−−Food and Drug Administration

FSMA−− Food Safety Modernization Act

FSSC 22000−−Food Safety System Certification

GAP−−Good Agricultural Practice

GMP—Good Manufacturing Practice

GLOBALG.A.P. −−Global Good Agricultural Practices

HACCP−− Hazard Analysis and Critical Control Point

International Accreditation Services—International Accreditation Services

IFS−−International Featured Standards

ISO 22000−−International Organization for Standardization

SQF−−Safe Quality Food

USDA−−U.S. Department of Agriculture

APPENDIX 2. THE LIST OF CERTIFICATION BODIES AND THE CORRESPONDING

Certification Body Code	Certification Body Name
1	AIB International
2	BSI Group
3	BM Trade
4	Bureau Veritas Certification Denmark
5	Bureau Veritas Certification UK
6	Cert-ID
7	DFA Global Certifications
8	DNV GL Business Assurance Italia
9	DQF CFS GmbH
10	Eagle Food Registration
11	Eurofins
12	Exova BM Trade
13	Food Safety Net Services
14	FoodChain ID Certification
15	Global Quality
16	ITS Testing Services
17	Intertek China
18	Intertek Certification
19	Kiwa Agri Food
20	LSQA
21	Mérieux NutriSciences Certification
22	NSF Certification UK
23	NSF Certification
24	Perry Johnson Registrations
25	ProCert AG
26	QMI-SAI Global Canada
27	QMI-SAI Global USA
28	SAI Global Certification
29	SCS Global Services
30	SGS Italia SpA
31	SGS United Kingdom
32	Safe Food Certifications
33	Silliker Global Certification Service
34	TÜV NORD CERT GmbH
35	TÜV NORD INTEGRA bvba
36	WQS CERTIFICAÇÕES LTDA
37	WQS
38	BQB-Gertificaiton

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WORKING PAPERS

Hu, L. and Zheng, Y. Within- or Cross-Brand Substitution? Quantifying the Impacts of Similac Infant Formula Recall (Under review, *Journal of Agricultural and Resource Economics*).

Nemati, M., Zheng, Y., Zare, S., and **Hu, L.** U.S. Organic Operations' Choice of Certifiers: Inertia and Neighbors Effect (Under review, *Food Policy*).

AWARDS AND GRANT PROPOSALS

University of Kentucky Conference Travel Awards, 2019

Proposal to USDA Agriculture and Food Research Initiative (AFRI) Competitive Grants (Unfunded), RA, 2018

Proposal to Food Connection at the University of Kentucky (Unfunded), Student PI, 2018