An Integrative Methods Investigation of Microbial Food Safety and Risk Management in the Maryland Direct-Market Poultry Supply Chain

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Abstract: The goal of my dissertation was to explore the Maryland direct-market poultry supply chain in order to describe and characterize factors of this system that are potentially related to microbial food safety of poultry meat products, focusing particularly on the issue of consumer exposure to multidrug resistant (MDR) foodborne pathogens through this supply chain. Rates of foodborne infections and illness resulting from human exposure to MDR livestock-origin bacterial pathogens are increasing in the US; characterizing the epidemiology of antimicrobial-resistance in the microbiome of livestock-associated pathogenic and non-pathogenic bacteria in the US food supply chain is a critical issue for public health. The conventional model for industrial-scale broiler poultry production has been demonstrated to facilitate selective pressure for antimicrobial resistance among foodborne pathogens in high-density livestock production environments. Existing alternatives to conventional, industrial-scale model for poultry production have not been evaluated in the same context. Prevalence and epidemiology of antimicrobial-resistant foodborne pathogens, along with more generic microbial food safety risk issues in small-scale commercial poultry production have not been adequately explored in scientific research. Moreover, the factors that differentiate industrial-scale and small-scale poultry production that may also be related to consumer food safety risks have not been described; the relevant context for developing informed research questions for the purpose of exploring microbial food safety issues in small-scale commercial poultry agriculture is unclear.

I used an integrative, mixed-methods research strategy to better understand food safety risks at the retail level of the Maryland direct-market poultry supply chain. I planned this research
in three stages; each stage employed a different method for collection and analysis of a unique data source, all taken within a single study population. In the first research stage, I conducted in-depth, open-ended interviews with small-scale commercial broiler poultry farmers who retail their products in the Maryland direct-to-consumer supply chain to gather qualitative data on topics related to microbial food safety. In the second stage, I used qualitative data from these interviews to develop a survey questionnaire tool to gather information on the methods and models of poultry production in use in Maryland, focusing on characteristics identified during the first stage of key informant interviews as relevant to microbial food safety. In the third stage, I purchased samples of retail meat in a market-basket analysis from a representative proportion of the statewide population of direct-market poultry retailers and analyzed for prevalence and antimicrobial-susceptibility patterns of common poultry-associated foodborne pathogens. Throughout this process, I addressed the policy relevance as well as the public health significance of all food safety-related findings.

This dissertation work is the product of an integrative methods research strategy to describe and contextualize the complex phenomenon of antimicrobial resistance among foodborne pathogens in the novel environment of a statewide direct-market commercial poultry supply chain. This dissertation represents, to the best of my knowledge, the first in-depth evaluation of these food safety issues in any direct-market commercial supply chain for these consumer products.

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Acknowledgements and Dedication

I am not one of those among my colleagues who always knew I would be Dr. So-And-So by age 30, or ever for that matter. But when the moment arrived, I chose this path and followed it for four years. Looking back on that time, I have come to realize that at almost every stage of this journey (and there have been many) I have felt different motivations compelling me to invest my mind, body and spirit in this work. Desire for the respect and authority awarded by society to scholars and certified experts on the mysteries of science and human health was an early motivation that quickly lost its luster. As we know, paid climate change deniers and anti-vaccine internet memes frequently enjoy credibility that can outweigh even the most passionate and informed public health advocacy. Similarly, the starry-eyed notion of “saving millions of lives at a time” came to feel slightly incongruous over time with the daily reality of what one of my mentors christened the “hamster wheel” of public health research: constant running, often with little (if any) tangible progress to show for it. This marathon ultimately leaves little room for romanticism or ego-worship. As I think is frequently the case with intense, long-term personal engagements, coming to the end has yielded yet another new perspective on the significance of the last four years. I have come to learn that it is the *process* of this task that is far more important to me than the presumed goal or endpoint of the process. Goals can shift with changes in the wind, or when new information is incorporated into an existing body of research. I have learned over the last four years that holding deep attachment to any single or idealized outcome for one’s endeavors can become a regular exercise in disappointment.
As of this moment of writing, I hold no clearly-defined idea of what I will do and where I will go, professionally and personally, after my rapidly-dwindling PhD career is concluded. It's a somewhat daunting reality to admit. However, I recognize that the significance of this moment is not in the supposed endpoint of having more letters after my name, or in knowing exactly where I will be a year from now. For me, the meaning of this moment exists in the ways in which the constant rigor and depth of this process has shaped me over all the previous moments. Somewhere in the daily intensity of the last four years, I became prepared to step into the insecurity of an uncertain future, filled with hope and equipped with the tools to learn and grow more. Maybe even make a contribution to...well, probably not saving millions of lives before breakfast, but maybe towards engineering little parts of the big systems to work better for the health and well-being of more people. Opportunities abound in uncertainty.

The path only continues from here. I am empirically older, and have upped my prescription for my glasses twice in three years. But beyond the odd gray hair and intensifying myopia, this experience has made me stronger, faster, better. I feel equipped for the unknown. I am grateful to have reached this point, and I am ready.

A great many people are responsible for bringing to this process all of the life and meaning I have been able to glean from it, and I would have never been able to get to this point without their support, dedication, guidance and friendship. I feel a deep gratitude to a great many, and will name a few here.

Dr. Meghan Davis must be acknowledged as the person most singly responsible for my education, training, and professional growth over the last four years. From before the first day of my PhD program up to the impending final day, she has been the finest mentor any
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It’s been a long road, and we aren’t home yet. Thank you, everyone, for helping me along this journey. Now it’s time to talk about the birds and the bugs that I found while I was traveling.
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List of Acronyms

USDA: United States Department of Agriculture
FSIS: Food Safety Inspection Service
CDC: Centers for Disease Control and Surveillance
MDR: Multidrug Resistant/Resistance
MDR-SA: Multidrug Resistant *Staphylococcus aureus*
MRSA: Methicillin-Resistant *Staphylococcus aureus*
MSSA: Methicillin-Susceptible *Staphylococcus aureus*
CLF: Center for a Livable Future
NARMS: National Antimicrobial Resistance Monitoring System
FDA: United States Food and Drug Administration
JHSPH: Johns Hopkins School of Public Health
IRB: Institutional Review Board
LA-: Livestock-Associated
CA-: Community-Associated
HA: Healthcare-Associated
CSA: Community Supported Agriculture
MDA: Maryland Department of Agriculture
PPIA: Poultry Products Inspection Act
HACCP: Hazard Analysis and Critical Control Plan
SSOP: Standard Sanitary Operating Procedure
GMP: Good Manufacturing Practices
AMR: Antimicrobial Resistant/Resistance
UV: Ultraviolet
OFPP: On-farm Poultry Processing
IQR: Inter-quartile Range
FT: Full-time
PT: Part-time
CPS: Coagulase-positive *Staphylococci*
CNS: Coagulase-negative *Staphylococci*
HGT: Horizontal Gene Transfer
QC: Quality Control
LOD: Limit of Detection
OR: Odds Ratio
CI: Confidence Interval
UTI: Urinary Tract Infection
STEC: Shiga-toxigenic *Escherichia coli*
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Chapter One

Introduction
1.1 Introduction and Background Issues

The goal of my research was to use integrative methods to explore and describe the microbial food safety landscape of Maryland’s direct-market poultry meat supply chain, focusing on the factors and outcomes associated with contamination of consumer poultry products with multidrug-resistant strains of common foodborne pathogens.

*Microbial food safety in US poultry*

Microbial food safety in the US poultry supply chain has long been recognized as an important public health issue by both policymakers and public health professionals. A review of food safety outbreak data in the US from 1998-2008 indicate that poultry contaminated with pathogenic bacteria was responsible for an estimated 653,622 cases of foodborne illness annually, comprising 17.9% of foodborne illness cases caused by exposure to bacteria [1]. The United States Department of Agriculture (USDA) and its Food Safety Inspection Service (USDA-FSIS) have developed federal regulations for poultry inspections and food safety standards enforcement [2] to reduce the risks of foodborne disease outbreaks from exposure to contaminated poultry products. One recent review demonstrated that poultry meat is the food product implicated in the greatest number of outbreaks of foodborne illness in the US from 1998-2008, and that poultry-borne Salmonellosis was the third-most commonly identified source of foodborne illness during the same period [3]. Attention to poultry contamination is particularly timely given the documented increase in antibiotic resistant genes in bacterial pathogens—including the microbial community associated with poultry carcass contamination. This trend represents a widely-recognized growing public health issues [4, 5, 6, 7, 8].
Market-basket studies of the US industrial poultry supply chain have demonstrated that retail poultry products are frequently contaminated with drug-resistant and drug-susceptible strains of microbial pathogens such as *Salmonella spp.* [5, 9, 10], *Campylobacter* [5, 11], *E. coli* [4, 5], *Staphylococcus aureus* [8, 12, 13] and other microbial foodborne pathogens [5].

Analyses of food safety risks in the US poultry supply chain exist in the literature. Volkova *et al.* analyzed factors related to *Salmonella* in poultry litter and live chick GI tracts at the production level [14, 15]. Sapkota *et al.* evaluated rates of drug-resistant *Enterococci* and *Salmonella spp.* at industrial poultry farms that transitioned to USDA Organic practices, which prohibit usage of pharmaceutical antibiotics in livestock production [16]; the study observed lower rates of drug-resistance in the farm environments of USDA Organic operations [17, 18]. Stern *et al.* analyzed *Campylobacter* concentrations in fecal samples from live poultry taken just prior to slaughter and compared these results to enumerations of *Campylobacter* taken from pre- and post-chilled poultry carcass samples derived from the same birds from which fecal samples had been obtained. Their findings suggest a system of complex and interactive parameters, yet to be fully described, that affect risks of microbial carcass contamination between the production and slaughter/processing stages [19]. However, none of these studies have included any analyses of the direct-market poultry supply chain, which is distinct from the industrial supply chain in many aspects that potentially impact food safety outcomes, particularly with regard to the prevalence and distribution of antibiotic resistance phenotypes among foodborne pathogens.

A small number of studies that are highly limited in scope have analyzed small-scale poultry production and processing from a microbial food safety perspective. One study sampled two farms with pastured poultry operations and collected environmental samples to analyze for
the prevalence of *Salmonella* spp. and to evaluate antibiotic-resistance profiles of positive isolates [20]. The same study purchased local “pasture-raised” poultry products (not from the same farms where environmental sampling had occurred), and tested them for the same microbial endpoints. The study demonstrated that the pasture-raised poultry products were positive for *Salmonella* spp. at a rate of around 50%, and that around 10% of these isolates were multidrug resistant. Farm environmental samples tested positive at a much lower rate (25%), and exhibited similar rates of multidrug resistance. These prevalence rates of resistant and susceptible *Salmonella* isolates are significantly lower than the averages observed in retail poultry meat products from the industrial supply chain. However, the retail meat samples in this study were not purchased from the direct-to-consumer supply chain, and were instead purchased from the smaller, niche-market end of the industrial poultry supply chain. Trimble *et al.* sampled the processing environment of small-scale poultry processors for *Salmonella* and *Campylobacter*, and demonstrated the presence of these pathogens in offal from carcasses and in on-farm carcass compost soil, but the study did not test for antibiotic resistance among positive isolates, and did not sample retail meat products [21]. One study from Pennsylvania [22] collected and analyzed microbial data from market-basket poultry meat samples and reported high prevalence of contamination with *Campylobacter* (85%) and prevalence of non-typhoidal *Salmonella* (28%) that was roughly equivalent to trends observed in other research [23, 24]. However, this single study had many limitations, including not testing for antimicrobial susceptibility among positive isolates. This study, which to the best of our knowledge represents the only other research containing a market-basket analysis of the direct-market poultry supply chain, is discussed further in Chapter Five.
Antimicrobial resistance among livestock-associated bacteria in industrial food animal production

Industrial-scale poultry production is typically characterized by two factors that together are understood to play an important role in driving selective pressure for antimicrobial resistance among foodborne and zoonotic microbial pathogens: 1) high-density and high-volume livestock production and; 2) regular use of subtherapeutic antimicrobial feed inputs for livestock disease treatment, prophylaxis and growth promotion [25, 26, 27, 28, 29]. This phenomenon was documented in the US supply chain as early as the 1950s, when usage of antimicrobials in food animals was just beginning to become widespread. In 1951, the first case documenting the potential for drug use in livestock production to drive antimicrobial resistance among microbial populations in the livestock production environment was published: a report on streptomycin resistance among coliform bacteria isolated from domesticated turkeys that had been given streptomycin in feed supplements [30]. The same phenomenon of usage of subtherapeutic feed antimicrobial inputs in livestock production driving bacterial resistance to antimicrobials would later be documented for the zoonotic and foodborne pathogen *S. aureus* in US swine and poultry production [31].

Public health concerns for antimicrobial resistance among foodborne pathogens

Antimicrobial resistance among foodborne bacterial pathogens is a serious complicating factor in foodborne illness; antimicrobial-resistant infections resulting from human exposure to foodborne bacteria caused an estimated 430,000 illnesses in the US in 2012 [32]. Beyond immediate food safety concerns, industrial livestock farms may serve as an incubator and reservoir for pathogenic and non-pathogenic drug resistant strains of livestock-associated bacterial species. US food systems and supply chains are large, complex, interconnected, and shares a potential pathway for transmission of bacterial species into many other ecological and anthropological environments where new populations of humans and animals may be
exposed. Two separate theoretical frameworks describe how human exposure resulting in colonization or infection with livestock-origin microbial species may occur, including strains of bacteria that have acquired resistance to antimicrobials in the on-farm environment. Evidence supporting the validity of both of these exposure scenario frameworks exists in the research literature. Under the first scenario, (1) colonization or infection may occur through direct human exposure to livestock-origin bacterial pathogens at any stage of the US food supply chain. Included in this direct-exposure framework are routes such as: handling of contaminated food products [33, 34]; occupational exposures in livestock production, slaughter, processing or handling [35, 36, 37, 38, 39]; or other direct exposure routes [40].

Under the second scenario, (2) livestock-origin microbial species are transferred into off-farm environments where subsequent colonization or infection of human and animal populations may occur. Potential exposure routes for this framework that have been evaluated in research literature have frequently focused on the potential for transfer of livestock-associated methicillin-resistant *S. aureus* (LA-MRSA) into households and communities via occupationally-exposed and colonized workers [41, 42, 43, 44]. Other theorized routes of off-farm transmission for livestock-origin microbial pathogens resulting in human exposures that have been explored include environmental transfer through surface waters to recreational beaches [45], through aerosolized particles and dust carrying viable pathogens that can be carried downwind from high-density livestock production facilities or livestock transport vehicles [46, 47] and through other routes of environmental transport or drift [48].

*Direct-to-consumer agriculture in the US food system*

Direct-to-consumer, or direct-market, agriculture describes the alternative system of agricultural production that markets local food products through direct sales at on-farm
retail stands, farmer’s markets, community-supported agriculture (CSA) programs, farm-to-table restaurants, local food hubs and other such outlets. Sales through direct-to-consumer agriculture channels have been rapidly increasing in recent years in the US food system. According to an analysis of data from the 2007 USDA Census of Agriculture, direct-to-consumer sales grew from $404 million to $1.2 billion from 1992-2007 [49]. This market growth was double that for total agricultural sales over the same period. Using different criteria (which include sales direct to local restaurants, institutions, and secondary retailers and distributors, as well as local consumers), sales of local agricultural goods in 2008 were estimated to be $4.8 billion [50]. From 2006-2013 the number of nationally registered farmers’ markets nearly doubled from 4,385 to 8,144 [49]. Though recent expansion of direct-market agriculture has been notable, direct-market sales account for a tiny portion (0.4% in 2007) of total agricultural retail in the US [50].

Policy and regulation
The USDA-FSIS is responsible for inspection of all poultry processing operations retailing more than 20,000 birds per year. For poultry processing operations retailing fewer than 20,000 birds per year, the federal government does not require inspection and these operations are considered “FSIS-exempt”. Poultry meat products processed at FSIS-exempt facilities cannot be sold outside the state in which they are grown or to any secondary retailer (such as supermarkets). States are authorized to develop and implement their own regulatory and inspection requirements for FSIS-exempt poultry processors to sell poultry meat legally within the state where they are located. Every state has some kind of regulatory infrastructure regarding FSIS-exempt direct-market poultry sales, but the requirements of the various statewide policies are different in each state, and may frequently change or be updated.
In Maryland, meat chickens (or broiler poultry) are one of the few types of livestock that can be legally slaughtered and processed for in-state sale without USDA-FSIS inspection and supervision, provided the retailer does not sell more than 20,000 birds per year; rabbits are the only other livestock covered by this exception to federal oversight. The Maryland Department of Agriculture (MDA) has developed, and in 2010 implemented a food safety inspection and training program for FSIS-exempt poultry processors. FSIS-exempt poultry processors who have not completed the certification may only legally sell their poultry products at on-farm stands. Processors certified under the MDA’s program are permitted to sell poultry meat products at farmer’s markets, to restaurants, and at other off-farm retail locations. The certification does not allow for sale to secondary retailers; all sales under MDA certification are direct-to-consumer [51].

Qualitative Research

Some qualitative research on occupational health issues related to poultry production and processing has been performed in the US [52, 53, 54], but the public health scope of this research has not generally included consumer food safety related issues. One qualitative study conducted in-depth interviews with California small-scale pastured poultry producers and marketers. This research sought to evaluate the perspectives and opinions of individuals within this commercial population on a wide variety of issues, including: best management practices, value systems and reasons for getting into alternative animal production, and benefits and challenges of small-scale pastured poultry production [55]. To the best of our knowledge, this is the only other published qualitative research that focuses on the motivations and perspectives of small-scale poultry farmers, and this research only contains a brief discussion and analysis of participants’ perspectives on food safety issues. To the best of our knowledge, no qualitative research analyzing the perspectives of commercial poultry
producers and processors on food safety and risk management in the industrial or direct-market poultry supply chain has been published in the US.

1.2 Summary and research goals

Direct-market agriculture, including the supply chain for poultry meat, is increasing in scale and market share in Maryland and other states. There is a distinct lack of public health research on food safety in direct-market poultry supply chains. The food safety research that has been done on the industrial-scale supply chain for poultry meat and other animal products cannot be used to evaluate these same issues in the direct-market supply chains. There are many factors and characteristics intrinsic to each supply chain that differentiate large and small poultry operations and may be associated with important microbial food safety outcomes including contamination of consumer poultry products with MDR pathogenic bacteria. The factors that differentiate small-scale direct-market poultry production and processing from the industrial scale have not been studied. To begin to address this research gap, I employed an integrative methods strategy that used a combination of in-depth interview data, survey questionnaire data, and a market-basket microbial analysis to explore and describe the microbial food safety landscape of Maryland’s direct-market poultry meat supply chain, focusing on the factors and outcomes associated with contamination of consumer poultry products with multidrug-resistant strains of common foodborne pathogens. This dissertation research has five specific aims: (1) Qualitatively describe the landscape of Maryland direct-market poultry producers and their operations, focusing on the factors and characteristics that differentiate the direct-market supply chain from the industrial poultry supply chain, and which may be associated with food safety outcomes; (2) Assess the perspectives of Maryland direct-market poultry retailers on state and federal food safety policy governing the statewide direct-market poultry supply
chain; (3) Qualitatively describe the opinions, awareness and perspectives of Maryland direct-market poultry producers on food safety risks, risk management strategies, motivations for minimizing food safety risks and other related issues in the statewide direct-market supply chain; (4) Quantitatively describe the frequency and distribution of poultry production models, slaughter and processing practices, on-farm inputs, and other key characteristics of small-scale poultry farming potentially relevant to microbial food safety outcomes among the statewide population of direct-market poultry retailers; (5) Employ a market-basket analysis to describe the prevalence of *Salmonella* spp., *E. coli*, and *S. aureus* and the antimicrobial-susceptibility profiles of all positive isolates recovered from a representative sample of the population of poultry retailers marketing in Maryland’s direct-market poultry supply chain.

The data used to fulfill the requirements of research aims 1-3 were collected by performing open-ended in-depth interviews covering these topics within a sub-sample of Maryland direct-market poultry farmers. Research aims (1) and (3) are addressed in Chapter Two; research goal (2) is covered in Chapter Three. Research goal (3) is further explored in Chapter Four with analysis of the interview data wherein participants describe specifics of food safety risk management strategies and process controls. The data obtained from research goal (3) were used to develop a survey questionnaire covering specifics of poultry production models, slaughter and processing practices, on-farm inputs, and other key characteristics of small-scale poultry farming potentially relevant to microbial food safety outcomes. This survey was applied to a sample of the study population of Maryland direct-market poultry retailers to achieve research goal (4); the results are described and analyzed in Chapter Four. Finally, research goal (5) was achieved by purchasing a market-basket poultry meat samples from the Maryland direct-market supply chain and performing a laboratory microbial analysis for prevalence and antimicrobial-susceptibility phenotypes of isolates of
Salmonella spp., E. coli, and S. aureus recovered from raw poultry meat products. These results are reported and analyzed in Chapter Five. For the conclusion in Chapter Six, I interpreted and integrated all previous results and analysis in the context of the broad issues underpinning microbial food safety in poultry production and processing generally, and specifically focusing on the phenomenon of antimicrobial resistance trends among foodborne pathogens. I further interpreted our findings on the direct-market poultry meat supply chain in the conclusions by comparing the findings from this supply chain to typical results observed in the industrial supply chain. I then discussed the public health and policy significance of our research findings, and described potential next steps for future research building on the findings of this dissertation.
Chapter Two

**Manuscript One:** Awareness and Perceptions of Food Safety Risks and Risk Management in Poultry Production and Slaughter: A Qualitative Study of Direct-Market Poultry Producers in Maryland
Abstract: The objective of this study was to document and understand the perceptions and opinions held by small-scale poultry producers who market directly to consumers on issues related to microbial food safety risks in the Maryland broiler poultry supply chain. Between January, 2014 and November, 2014, we conducted semi-structured, in-depth interviews with a convenience sample of 16 owner-operators of Maryland direct-market commercial poultry farms. All have experience with food safety in the statewide direct-market poultry supply chain. Three overarching thematic categories emerged from these interviews: descriptive characteristics of Maryland direct-market poultry production and processing; microbial food safety risk awareness and risk management in small-scale poultry production, slaughter and processing; and motivations for maintaining food safety in the statewide direct-market poultry supply chain. These three categories were organized into eight distinct subcategories. The findings have policy implications and provide insights into food safety in small-scale commercial poultry production, processing, distribution and retail. In addition, the findings will inform future food safety research on the small-scale US poultry supply chain.
2.1 Introduction

2.1.1 Qualitative Environmental Health Research on US Poultry Production

Some qualitative research on occupational health issues related to poultry production and processing has been performed in the US [1-3], but the public health scope of this research has not generally included consumer food safety related issues. However, this research was useful in developing a general understanding of the production and processing environments as well as a framework and some lines of inquiry for the interview guide employed in this study.

One qualitative study we reviewed conducted in-depth interviews with California small-scale pastured poultry producers and marketers. This research sought to evaluate the perspectives and opinions of individuals within this commercial population on a wide variety of issues, including: best management practices, value systems and reasons for getting into alternative animal production, and benefits and challenges of small-scale pastured poultry production [4]. To the best of our knowledge, this is the only other published qualitative research that focuses on the motivations and perspectives of small-scale poultry farmers, and this research only contains a brief discussion and analysis of participants’ perspectives on food safety issues. However, this research was very useful in developing lines of questioning for these interviews, and can be a useful companion data set for the analysis performed in this research.

To the best of our knowledge, no qualitative research analyzing the perspectives of commercial poultry producers and processors on food safety and risk management in the industrial or direct-market poultry supply chain has been published in the US.
Direct-market agriculture, including the supply chain for poultry meat, is increasing in scale and market share in Maryland and other states. There a lack of public health research on food safety in direct-market poultry supply chains. The body of research evaluating microbial food safety issues the industrial-scale supply chain for poultry meat and other animal products cannot be extrapolated to these same issues in the direct-market supply chains. There are many factors and characteristics intrinsic to each supply chain that differentiate large and small poultry operations and may be associated with important food safety outcomes, including microbial contamination of poultry products with pathogenic bacteria, including antibiotic-resistant foodborne pathogens. The factors that differentiate small-scale direct-market poultry production and processing from the industrial scale have not been studied. By analyzing data obtained through semi-structured, open-ended interviews with Maryland commercial direct-market poultry suppliers, this pilot study will begin to address this gap in the literature. Specifically, this paper will: 1) Describe the landscape of Maryland direct-market poultry producers and their operations with specific attention to the factors and characteristics that differentiate this direct-market supply chain from the industrial poultry supply chain, and which may be associated with food safety outcomes; 2) Document the opinions, awareness and perspectives of Maryland direct-market poultry producers on food safety risks, risk management strategies, motivations for minimizing food safety risks and other relevant related issues in the statewide direct-market supply chain.

2.2 Methods

In order to document and describe the perspectives and opinions of owner-operators of commercial poultry production facilities in Maryland on these issues, we conducted a series of in-depth interviews with producers. We identified participants via publicly available
commercial registries and documents, including the MDA Rabbit and Poultry On-Farm Processing Database, and more than 20 other commercial self-registries that promote and advertise direct-market agricultural producers in Maryland. A complete list of the commercial registries used to identify potential participants is included in Appendix A. As a secondary strategy, we used snowball sampling [5] to identify participants whose contact information was not available through the aforementioned sources. Participants were recruited via email or phone contact, and offered a $20.00 cash incentive to participate. The lead author conducted all of the interviews at places convenient for the interviewees (on-farm or in a coffee shop).

We developed an interview guide that included open-ended questions organized under the following three categories and eight sub-categories of thematic content, described in Table 2-1. The questions were designed to elicit information and responses on the Maryland direct-market poultry supply chain, focusing in particular on issues related to food safety risks in poultry production. The routes of questioning used in these interviews were developed using several different sources of information. Some questions were developed from information and insights gathered from informal conversations with policymakers (MDA employees responsible for administering the Rabbit and Poultry On-Farm Processing Certification program), as well as informal conversations with a convenience sample of two small poultry farmers in Southern New Jersey, and one small poultry farmer in Virginia who are professional contacts of the investigators. Other lines of questioning were drawn from a review of existing food safety literature on the small-scale poultry supply chain [6, 7, 8] and the USDA-FSIS inspection criteria for poultry processing facilities [9]. The single qualitative study of California pastured poultry farmers was also useful for developing questions used in the interviews [10].
Interviews were transcribed verbatim with the interviewees’ permission, then coded and annotated to highlight important topics and observed patterns in the qualitative data. These coded interviews were further analyzed to assess the frequency and strength of particular themes, opinions and perspectives in accordance with standard qualitative data analysis techniques [11].

The Johns Hopkins Bloomberg School of Public Health Institutional Review Board approved this project.

2.3 Results

Following are the results of the recruitment and thematic analysis of the interview data. The results are organized along the following general topics: observations and descriptions of intrinsic factors and attributes of the direct-market poultry production supply chain in Maryland; descriptions of and perspectives of on-farm commercial poultry slaughter and processing; awareness and perceptions of food safety and risk issues related to microbial contamination in small-scale poultry production and slaughter, particularly antibiotic-resistant foodborne pathogens; and motivations for maintaining food safety and quality control among direct-market poultry retailers.

2.3.1 Enrollment and Recruitment

We invited 43 eligible participants to be interviewed via email requests. Twenty-one people responded, and one declined to be interviewed. Of the remaining 21, four expressed interest but did not meet the inclusion criteria; two were not yet commercially active, one raised and processed only turkey and exotic waterfowl. We were unable to follow up with the last respondent because he appears to have sold his farm and left the state in the interim between first email contact and follow-up contact via phone. We completed interviews with
sixteen respondents between January, 2014 and November, 2014. The interviews lasted between 30 and 120 minutes, and averaged 75 minutes. Table 2-2 describes some demographics of the participants.

2.3.2 Topic 1: Direct-market poultry in Maryland

Participants described their poultry operation, their experiences in direct-market agriculture, as well as more general perceptions and opinions on the statewide direct-market poultry supply chain. The lines of inquiry were designed to highlight areas that participants considered to be unique to direct-market poultry production (and which distinguish small-scale from industrial-scale poultry operations), and to focus on the characteristics of the direct-market poultry supply chain that participants considered to be important or related to food safety.

2.3.2.1 Professional experience

Many participants were new to poultry farming, with 11/16 having ten years or less experience in commercial direct-market poultry production. Five participants were in their first 36 months of engaging in any kind of commercial agriculture production at the time of the interview. A large majority (13/16) of the participants entered commercial poultry farming from another professional background. Participants’ previous occupations included: school bus driver, fishing boat captain, senior officer at a federal regulatory agency, corporate sales, manager of a fast food restaurant, DJ and local radio personality, high school science teacher, veterinarian, and as a military officer. About one-third of participants were highly experienced farmers, sometimes with decades of personal experience and usually with a family history of farming in Maryland. Three participants were self-described “lifelong farmers”, who had held no other long-term occupations.
2.3.2.2 Economics of direct-market poultry production and agriculture

There was broad consensus among participants that small-scale poultry production was relatively inexpensive to start, with low startup costs for animals and infrastructure, and that the practices for successfully raising small flocks of poultry livestock were easy to learn. However, there was equally broad consensus that raising poultry, even in very small numbers, required a large commitment of time and energy, if not capital. Many farmers cited the 7-12 weeks required to raise broiler poultry to the weight where they can be slaughtered and sold as a relatively quick turnaround. All agreed that there was a large demand for direct-market poultry among their consumer base. However, every participant described broiler poultry as a low-margin product for profit, even at price points significantly higher than those of supermarket poultry meat products. Despite the perception of poultry as a low-margin product, there was consensus among participants that the low overhead and startup costs, as well as the relatively simple skill sets required, makes direct-market poultry attractive for farmers, particularly those newer to farming, or growing a newer business.

Participants described highly diversified models for their agricultural production and sales, into which the quick cash returns and low startup and overhead costs of small-scale poultry production were integrated. None of the participants sold poultry meat products exclusively; all commercially raised other livestock (laying hens, ducks, geese, guinea fowl, lamb, beef and dairy cattle, swine, goats, alpaca, emu, horses, cats, and dogs) on the same property where broiler poultry were kept. Many participants also sold a variety of produce and animal products such as milk, cheese, eggs and processed meats such as bacon, sausage, and cured and dried meats. Many participants also explained their decision to not use or to limit use of
antibiotics in their livestock and poultry production as customer-driven. Direct-market consumers are only willing to pay higher prices for poultry that is antibiotic-free.

2.3.2.3 Pastured poultry
All participants except three described their poultry production model as a “pasture-based” system in which poultry are kept in mobile housing and rotated through different paddocks of open pasture. The remaining participants described a model wherein small flocks of poultry are kept in permanent, non-mobile housing and are given daily access to the outdoors. Both of these direct-market models differ dramatically from the all-indoor, high-density and high-scale poultry production models typically employed in industrial-scale poultry production. Pasture-based systems frequently involved rotating poultry over the same parcels of land over time in a structured land management system. Participants described this system as efficient and clean. They also described the rotating pasture system as one that kept animal manure from concentrating on their grazing lands, and kept the poultry livestock cleaner and healthier by constantly moving them away from their manure and onto fresh pasture. Many participants also explained that providing the livestock access to pasture where they can supplement their feed-based diet with more diverse forage helped to bring down feed costs and reduced risks of disease among their flocks.

2.3.2.4 On-farm poultry processing
Most participants maintain on-farm poultry slaughter and processing facilities that are integrated into their poultry production system. Participants described slaughtering and processing small flocks of poultry by hand as a relatively easy process to quickly learn how to do cleanly enough to provide acceptably safe products for sale to customers; but the same participants also generally noted that the same process takes time and practice to perform efficiently.
Most participants quoted the price of entry-level infrastructure, which generally included a stainless-steel table with a sink drain, a scalding tank, a motorized feather-plucker, a chilling tank, and a commercial freezer, at around $1,500-3,000 USD. Most, but not all, believed this to be relatively inexpensive overhead and startup cost to start an on-farm poultry processing facility capable of small-scale commercial operation. Many participants believed that the low costs and relatively simple set of skills and practices to learn were important reasons that many farmers, particularly new farmers, often incorporated on-farm poultry processing into their direct-market agriculture production models. As with small-scale poultry production, participants noted that time and energy, not capital, were the main inputs that made on-farm poultry processing difficult or burdensome. Processing was described as labor-intensive, time-intensive, exhausting, and even depressing.

“...if you look in the Bible, they rotated who was sacrificing and slaughtering animals for food. You know, it’s not good psychologically to do that every day...”

All participants acknowledged that there is a large amount of variability in the amount of capital that different Maryland on-farm poultry processors are capable of investing in their facility and equipment. This was commonly referred to as an “investment gap”, wherein farmers with less money to spend will purchase cheaper or used equipment, and may also construct and engineer functional alternatives to more expensive processing infrastructure out of repurposed or spare parts and materials. One participant who constructed a homemade feather-plucker out of a sawed-off plastic rain barrel and a repurposed lawn mower motor referred to his processing operation as “southern engineered”. While all participants acknowledged the existence of an investment gap, there was some disagreement as to whether or not this gap inherently affected microbial food safety and risks of cross-contamination during processing. The most common opinion among participants was that the slaughter practices and the attention to quality control were much more important than
the equipment that was being used for maintaining food safety during poultry processing. Most participants held the opinion that a conscientious processor could achieve acceptable food safety outcomes with a low-investment facility, but that maintaining food safety was simpler and easier with newer and more expensive equipment and infrastructure. Two participants believed that the investment gap was a potential contributor to food safety issues, with increased risk of contamination in a low-investment facility, but they also equivocated on that opinion by stating that they also believed workplace practices were much more important than infrastructure investment in determining food safety outcomes.

Three recurring and significant themes emerged when participants were asked about the reasons they chose to process their poultry on-farm, rather than seeking out a third-party processor. One common reason participants mentioned was a lack of available infrastructure; all participants noted that there are very few options in Maryland or the surrounding states for independent poultry producers to take their birds to be processed so they can be sold legally. All participants who used a third-party USDA-FSIS inspected processor took their poultry to the same single facility in Maryland. Many of the participants are in remote areas of Maryland that are far-removed from the existing third-party poultry processors who will accept their livestock. On-farm processing represents a realistic and cost-effective option for participants to legally process their poultry into a product for sale on the direct market.

The second reason cited for electing to process on farm was cost-control. Participants observed that poultry meat, already a low-margin product, became even more costly to produce when contracting a third party to slaughter and process the livestock. The poultry farmers who employ on-farm slaughter processing believed that this model created
opportunities to control this input cost. Conversely, the three participants who elected to use third party processors did so because they felt the extra cost was worth the time and energy required to slaughter and process poultry themselves.

The third and most pronounced recurring theme that participants cited as a reason for choosing to process poultry on-farm was quality control and food safety. Most participants who processed their own birds described the on-farm processing model as an integral part of a wholly different food safety risk management paradigm than the one applied in industrial-scale poultry production and processing. Specifically, participants observed that the industrial model allows for and assumes a high amount of microbial pathogenic contamination of livestock during production, and subsequently of carcasses during the initial and early stages of slaughter and processing. Participants opined that this system then relied on chemical disinfection at critical control points during slaughter and processing to reduce the food safety risks of widespread microbial contamination of post-processing consumer products. The conceptual model applied here could be simply characterized as, “dirty in, clean out”.

Participants described an alternative model employed in small-scale production and processing wherein the food safety paradigm operates on a fundamentally different principle. Multiple participants used the phrase “clean in, clean out” to describe this concept. Under this premise, integrating the best practices of small-scale poultry livestock husbandry with careful hand-work and rigorous quality control during slaughter and processing, along with enforcing meticulous biosecurity measures and active animal health surveillance (steps taken to quarantine or cull sick birds from the rest of a healthy flock and to control risks of outside contamination of on-farm production or processing infrastructure) results in a lower-risk, “cleaner” system throughout the production, processing and distribution continuum of the
direct-market poultry supply chain. Rather than assuming high levels of contamination that must be engineered out of the supply chain at critical control points (as in the industrial model), the “clean in, clean out” paradigm assumes low levels of contamination at all stages of production, and in the initial stages of slaughter and processing. This paradigm, which is unique to the smallest commercial scale, informs practices and food safety controls that are designed to maintain cleanliness (rather than to reduce widespread contamination) during production, processing and distribution to minimize risk and achieve food safety goals. Discrete functional aspects of the “clean in, clean out” system and its application to on-farm poultry processing are described in greater detail below.

Participants believed that processing small batches of poultry by hand at an on-farm slaughter facility was a time and labor-intensive activity when compared with processing larger flocks in a mechanized industrial-scale facility. However, slow speed and manual labor actually directly enable greater care and precision to be exercised during slaughter and processing to avoid microbial cross-contamination of facilities, equipment and carcasses, and reduce overall risks of contamination of consumer products. The concept of slow, careful hand processing and the connection to food safety risk reduction was also expressed in the context that this model allowed more time and opportunities for enhanced quality control and visual inspection of the product and the processing line to prevent adulterated poultry meat from reaching the consumer. The slow speed of the on-farm processing model allows direct-marketers to exercise a superior level of quality control through these dual mechanisms of accident reduction on the processing line, and early detection and remediation of cross-contamination issues. Participants maintained that this strategy to prevent microbial contamination of their poultry products enabled a higher level of food safety protection than would be possible at a larger or more mechanized facility.
“…there are just fewer eyes on each bird [at the industrial scale], the number of actual inspections of each bird is so much lower, like 0.1% of what we do...Compared to what we do...you get three sets of eyes on each bird, and that’s so important [for food safety].”

Intertwined with the importance of slower speed on food safety/quality control was the significance of slaughtering and processing poultry by hand. Hand processing is the meticulous collection of practices for manually killing, defeathering, eviscerating and packaging broiler poultry that are only possible when performed at a relatively slow speed, and a small scale. Hand processing is both endemic and unique (within the poultry slaughter industry) to the current practices of small-scale on-farm poultry processing. Participants contrasted this system to the highly mechanized and largely automated industrial-scale poultry processing facilities. The consensus opinion was that hand processing afforded many more opportunities for avoiding accidents that may compromise food safety during processing (such as a gut rupture) and to quickly remediate accidents of this kind that still may occur during processing.

“...they [on-farm processors] are doing it by hand for the most part...each carcass is handled on its own, all the cutting is done by hand. So you don’t see the number of accidental cuts to the intestines and stuff like that, as you would in an automated system. Because for one you’re processing a fraction of the number of birds, and also you’re trying not to hurt yourself...So that hand work, compared to the automatic systems, reduces the amount of bacterial meat contamination you’re going to see on the whole.”

Hand work also allowed increased opportunity for inspection of carcasses to detect any other adulteration.

On-farm poultry processors generally reported only processing their own livestock, although two processors described occasionally providing processing services for very small producers (usually neighbors) who were raising poultry for personal consumption, not retail. Participants described this exclusionary process as a “biosecurity” measure, designed to keep
any contamination or disease-causing agents from other farms or off-farm environments from compromising their production or processing system.

In general, participants’ various observations on this issue comprehensively identified the smaller scale of production and processing itself at the FSIS-exempt level of operation as a structural advantage for maintaining food safety and controlling risks of contamination of consumer products within this supply chain. This comprehensive factor of scale was connected to the speed at which processing occurred, the time dedicated to inspection and quality control, the practices and methods (such as hand work) that are employed, and the infrastructure and equipment of on-farm poultry processing.

2.3.3 Topic 2: Food Safety Risk Awareness and Perceptions

We asked participants about their perceptions and opinions of microbial food safety risks in small-scale poultry production generally, and employed follow-up lines of questioning to determine participants’ ideas and opinions on the relevant factors associated with microbial food safety in the Maryland direct-market poultry supply chain. Many of the participants described their operation or a typical Maryland direct-market poultry operation in contrast to their perception of a typical industrial-scale poultry operation.

2.3.3.1 Risk perceptions associated with the direct-market poultry supply chain

Participants had a high general awareness of microbial food safety risk issues associated with commercial poultry production and processing. They perceived livestock production and slaughter as a system with inherent food safety risks that must be mitigated in order to provide acceptably safe food to their customers. As one participant explained when asked about risks of pathogen contamination on poultry products:
“…when you’re talking about an omnivore that eats grain, and what they can have in their intestines, even if it’s the highest quality, sure there’s concern. And that’s why we take our processing so seriously, to make sure that food is unadulterated.”

Another participant put it more simply:

“…chickens are still just a pretty dirty animal no matter what you do.”

Interviewees conveyed a general perception that small-scale poultry slaughter and processing is a relatively simple system to control (compared to the industrial poultry processing systems) in terms of maintaining a clean facility and providing unadulterated poultry products to consumers. This sense was generally described in the context of size, and the benefits of small-scale and on-farm processing, covered in the section above.

Apart from the perception of lower overall risks of cross-contamination during slaughter due to scale-related factors, participants also expressed that the smaller scale of their operations reduces the impact of population exposure. If a processing-level contamination event does occur and adulterated products make it to the market, the exposure is easier to identify and control.

“…the scale we’re doing things at, I mean…the risks to people generally are just so much smaller than for Perdue if something does go wrong.”

However, many interviewees acknowledged that a lack of comprehensive regulation at the FSIS-exempt level of Maryland poultry processing and retail created the potential for food safety problems. Most of their concerns were for “bad actors”, or individuals who did not place the same priority on quality control and cleanliness. Interviewees expressed concern that inadequate regulations and enforcement regimes could enable these “bad actors” to introduce poultry products to the direct-market supply chain that are not processed under the same high standards that interviewees hold for their own operation and could compromise food safety within the Maryland direct-market supply chain. However, most
participants described this pool of “bad actors” as a very small portion of the people commercially engaged in this economy at the direct-market level in Maryland. Furthermore, they generally expressed confidence that the market would eliminate most operations producing inferior or unsafe products.

2.3.3.2 Antibiotic resistance and food safety in poultry production

Interviewees described a high level of concern when asked their opinion on the trends of antibiotic and antimicrobial resistance in foodborne pathogens, and the potential impact of these trends on public health.

“…the more things we eat that have antibiotics in them, the harder it is for us to fight off the resistant bugs that come down the food chain…things like MRSA and all sorts of horrible kinds of bacteria are out there now, and there are brand new ones all the time.”

Participants associated these trends with practices used in the industrial poultry production system, particularly the use of prophylactic and sub-therapeutic antibiotics. They considered antibiotic resistance in foodborne pathogens to be a problem associated with the industrial poultry supply chain, not the direct-market chain in which they are engaged. None of the participants used sub-therapeutic antibiotics in their poultry production system.

“…I see (antibiotic resistance in the food supply chain) as a huge problem. And I think it comes exclusively out of big companies that are raising confinement poultry and feeding them antibiotics…You know, they’re basically eroding the tools of humanity to keep ourselves from getting sick, and they’re doing it at everyone’s expense.”

Participants frequently mentioned feeling “insulated” from the problems of antibiotic resistance they perceived in the industrial poultry supply chain. Reasons mentioned for this perception focused on use of a model that reduced or eliminated the need for antibiotic or antimicrobial inputs during poultry production; strict implementation of biosecurity measures during production and processing; use of non-pharmaceutical methods for animal disease control such as active disease surveillance and culling and quarantining of sick birds; and careful sourcing of day-old broiler chicks.
2.3.4 Topic 3: Motivations for maintaining food safety

Many of these findings concern the structural differences between industrial-scale and FSIS-exempt direct-market poultry supply chains. In addition, participants shared personal motivations for maintaining food safety with equal weight when describing food safety in their operations. These personal motivations, according to participants, constitute a critical difference between the direct-market supply chain and the industrial supply chain.

Participants broadly expressed the opinion that direct-market poultry producers generally hold a higher personal standard for cleanliness and quality control in their products than industrial suppliers. These motivations, inherent in most small-scale and direct-market poultry producers, generally inform practices that provide for a lower-risk supply chain compared to the industrial model.

2.3.4.1 Elevated personal responsibility for food safety and quality control

Participants discussed several related motivations for direct-market poultry producers to practice higher levels of personal responsibility for quality control and food safety in their products relative to the industrial-scale poultry supply chain.

“…everyone that I know is actively involved in the process. And it’s usually the same person going down to sell the product at the farmer’s market...the responsibility and the accountability is really transparent...Which you don’t see in the industrial sector because it’s so compartmentalized. The grower is separate from the processor is separate from the distributor which is separate from the retailer. So you have people...who don’t really care about the other parts...of the supply chain, or feel responsible for them.”

Participants frequently discussed personal contact with their customers, and cited wanting to keep their customers satisfied as a major motivation for taking personal responsibility for providing the safest food possible.

“...small producers are more conscientious [than large producers] because they’re more in touch with their market. They’re more in touch with their consumers. It’s a face-to-face industry...It’s that customer contact you get with this scale that makes a difference. Otherwise it’s just a label in a supermarket.”
Every participant also reported consuming their own products, and many participants mentioned this as a major motivating factor for wanting to keep their products as clean as possible.

Direct-market farms are, generally speaking, small businesses that operate on tight financial margins, and depend on a reliable core base of customers to remain profitable. Participants in the direct-market supply chain described serving customers from tight-knit communities, wherein protecting one’s personal reputation for providing safe, high-quality food is critical to the survival of one’s business.

“I don’t have some big lobby… backing me and spending money to protect me. If something goes wrong… this is my livelihood, this is my family’s farm…”

Many participants emphasized the need to maintain a high level of trust and a good reputation for having safer, healthier food as a factor differentiating the direct-market poultry supply chain from its industrial-scale counterpart.

2.3.4.2 Transparency

Transparency, or freely offering information about the practices used in poultry production and slaughter and providing public access to the farm and processing environments, was a recurring theme among participants and was described as an integral aspect of the philosophy and practices that promote safer food products in this supply chain. This issue was seen as particularly important in Maryland because—from the perspective of many participants—this level of the poultry industry lacks comprehensive regulation. Transparency keeps small commercial operators “honest” and ensures they are using the practices desired by the most food-conscious consumers (those who would bother to ask in-depth questions of farmers and conduct a farm visit).
“...one of the things that the sustainable ag[riculture] community prides itself on is transparency. And that's the one tomato we're always throwing back at industrial ag[riculture], is that they don't let anyone behind those [expletive] doors. They wouldn't want you to look behind those doors. They want you to look at the paperwork.”

2.4 Discussion

2.4.1 Applications for public health research and policy

The overwhelming majority of research on the US food system has focused on the industrial-scale supply chain for poultry and other agricultural products. This study is, to the best of our knowledge, the first attempt to describe the models and practices in use in a statewide direct-market poultry supply chain. We believe this study also constitutes the first qualitative research to analyze the opinions and perspectives of the participants in this market on issues affecting food safety and public health. The data collected and analyzed for this project can provide important information and lay the groundwork for more in-depth research into the epidemiology of antibiotic-resistance, and other food safety and public health issues in the direct-market poultry supply chain for Maryland. This analysis may also be of use to public health research in other regional food systems and other agricultural paradigms, such as the direct-market supply chains for other livestock animals and animal products.

Policymakers in Maryland and many other states are in the beginning stages of developing effective food safety policies and regulatory strategies for these markets. For poultry, in the absence of leadership from the USDA, states are tasked with the difficult job of promoting small agricultural markets while protecting a growing number of consumers from potential food safety risks. The lack of public health research on these topics is a missed opportunity to inform this undertaking.
The analyses structurally differentiating Maryland’s large and small-scale poultry supply chains can be applied to inform future research into food safety risks in Maryland’s direct-market poultry system. These participants offer insights on the methods, models and characteristics of operations and their ideas of best practices for food safety in small-scale poultry production and processing. In particular, these interviews offer initial insights into the factors which may alter the risks of food supply chain contamination with antibiotic-resistant and susceptible foodborne pathogens in the direct-market supply chain as compared with the industrial poultry supply. This analysis can provide the groundwork for developing a more accurate and nuanced understanding of the structural factors affecting food safety outcomes among small scale producers. In the absence of reliable research defining microbial food safety risks in the direct-market poultry supply chain, the perspectives on these risks held by individuals with professional knowledge and experience can provide valuable insight to inform further investigations about this growing supply chain.

Findings regarding participants’ perspectives on personal motivations and value systems of direct-marketers related to food safety risks can also be applied to advance public health research. Further research on food safety issues involving direct-market agriculture systems will benefit from a deeper contextual understanding of the philosophical grounding and personal motivations of the commercial operators in this supply chain. Our analysis demonstrates that the philosophical perspectives of the direct-market supply chain often directly inform what practices, models and priorities are applied by the farmers themselves to food safety risk management in small-scale poultry production and processing. A contextual understanding of the priorities and choices of this routinely disregarded stakeholder
population is important for public health research for these reasons; this study offers a potentially rich source of data on an understudied population of these stakeholders.

As all of the poultry producers included in this research run highly diversified operations and are also direct-marketers of many other agricultural products, we also feel that these opinions and perspectives are likely to be relevant beyond the Maryland poultry supply chain and may be applicable in some regards to aspects of the regional direct-market supply chain for poultry and other agricultural products.

Limitations and areas for further research

The findings from this study are limited in some regards. While a sample size of 16 may seem like a low number, a broader survey of the Maryland direct-market poultry supply chain has identified fewer than 70 active participants in the direct-market poultry supply chain who met the inclusion criteria for this study. However, while this sample may be fairly representative of Maryland’s direct-market poultry supply chain, it is reasonable to assume that some issues related to both food safety risks and regulation may be considerably different in other regions of the US. However, it is possible that there may be a regional effect in the generalizability of these findings, wherein the issues and perceptions of those issues in comparable populations may be more similar in regions proximate to Maryland than in those more geographically distant. Further investigation into these topics should include states such as Delaware, Virginia, Pennsylvania and West Virginia to establish the validity of such a regional effect.

There may also be some response bias concerns in terms of only sampling among participants who volunteered to be interviewed. It is possible that such a response bias occurred, however, given that an estimated 20-25% of the extant population of direct-
market poultry producers were actually sampled as part of this study (as established by the broader survey of statewide poultry production we have administered), we feel confident that these findings are at least representative of a large portion of the overall population. However, further research should also be conducted to establish the extent of the validity of these findings within Maryland.

2.5 Acknowledgments

I would like to acknowledge Dr. Shannon Frattaroli, Dr. David Love and Dr. Meghan Davis for their comments, input and proofreading of this manuscript. Deanna Baldwin from MDA provided input in helping to craft the lines of inquiry used in the interview guide.

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2.6 References


[10] Hilimire K: The grass is greener: farmers’ experiences with pastured poultry. Renewable Agriculture and Food Systems: 27(3); 173–179

Table 2-1: Topics and Issues Raised During In-Depth Interviews

<table>
<thead>
<tr>
<th>Primary Topics</th>
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<tr>
<td>Maryland Direct-Market Poultry Supply Chain</td>
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<tr>
<td>Food Safety in Small-Scale Poultry Production and Processing</td>
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<tr>
<td>Motivations for Maintaining Food Safety</td>
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<td>Sub-Topics</td>
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<tr>
<td>Defining the landscape of Maryland direct-market poultry farming</td>
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<td>Characteristics of small-scale poultry production related to microbial food</td>
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<td>safety issues</td>
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<td>Economics of direct-market agriculture in Maryland</td>
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<td>Microbial food safety risks in direct-market poultry supply chain</td>
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<td>Comparing food safety issues between different models of poultry production</td>
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<td>Methods used to mitigate microbial food safety risks in small-scale poultry</td>
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<tr>
<td>production</td>
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<td>Perspectives on personal and professional reputation in direct-market</td>
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<td>agriculture systems</td>
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<td>Morals, ethics, and philosophy of small-scale poultry farming and direct-</td>
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<td>market agriculture</td>
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Table 2-2: Demographics and Background Characteristics of Study Participants

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<td><strong>Gender</strong></td>
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<tr>
<td><strong>Age (years)</strong></td>
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<td>Calvert (1/16)</td>
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Chapter Three

**Manuscript Two:** Perceptions on Federal and Statewide Food Safety Policy Among Direct-Market Poultry Producers in Maryland, USA
Abstract: The objective of this study was to document and understand how small-scale poultry producers who retail directly to consumers perceive and experience federal and state food safety policies. Between January, 2014 and November, 2014, we conducted semi-structured, in-depth interviews with a convenience sample of 16 commercial poultry production and direct-marketing operators in Maryland. All participants have experience in direct-market poultry operations commercially regulated under federal and state food safety policy. The findings provide insight into food safety policy in direct-market US commercial poultry production, processing, distribution and retail, and have implications for policy in this area.
3.1 Introduction

3.1.1 Direct-market poultry processing in Maryland

In Maryland, poultry is one of the few types of livestock that can be legally slaughtered and processed for in-state, direct-market sale without inspection and regulation by the United States Department of Agriculture Food Safety Inspection Service (USDA-FSIS). This exemption is only valid for small-scale poultry retailers, and specifically applies only to poultry retailers selling fewer than 20,000 birds per year. Meat rabbits are the only other livestock covered by this exception in Maryland [1]. Maryland law permits poultry sold directly to consumers to be slaughtered and processed through five mechanisms: 1) Process <20,000 birds per year at an uncertified facility on the farm where the birds are raised and sell directly to consumers from a retail location on the producer’s farm; 2) Process <20,000 birds per year at an MDA-certified facility on the farm where the birds are raised and sell directly to consumers anywhere in the state; 3) Hire a third-party poultry processor at an MDA-certified facility that processes <20,000 birds per year and sell directly to consumers anywhere in the state; 4) Hire a third-party processor with USDA certification who will process for independent poultry producers; or 5) Process poultry at an on-farm USDA-FSIS inspected and certified poultry processing plant. Processing at USDA-FSIS inspected facilities allows sale at all levels of the poultry supply chain, and is not limited to in-state or direct-to-consumer sales; USDA-FSIS inspection also removes the 20,000 birds/year limit on sales volume required for exempt retailers [2]. However, there are few USDA-inspected poultry slaughter and processing facilities in Maryland or in neighboring states who will accept live poultry from small, independent producers. To the best of our knowledge, there is only one third-party operated USDA-FSIS inspected poultry slaughter facility that will process birds for independent, direct-market poultry producers operating in Maryland during
the study period (2014-15). We established this by reviewing an online database of all the USDA-FSIS inspected poultry slaughter facilities in Maryland [3], and then calling the business telephone lines of all the listed facilities that slaughter and process poultry to ask if they worked with direct-market poultry producers. All telephone inquiries to businesses were answered, and only one facility in Maryland would accept live poultry from small direct-market producers was identified by this method.

3.1.2 Policy and Regulation Covering Direct-Market Poultry Sales

The USDA-FSIS is responsible for food safety inspections of all poultry processing operations retailing more than 20,000 birds per year. For poultry processing operations retailing fewer than 20,000 birds per year, the USDA-FSIS does not require inspection under the Poultry Products Inspection Act. Poultry processing operations retailing fewer than 20,000 birds per year are considered “FSIS-exempt”. Poultry meat products processed at FSIS-exempt facilities cannot be sold outside the state in which they are grown or to any secondary retailer (such as supermarkets) who will sell them outside the state [4].

States are authorized by USDA to develop and implement their own regulatory and inspection requirements for FSIS-exempt poultry processors to sell poultry meat legally within the state where they are located. Almost every state in the US has a policy covering FSIS-exempt poultry agriculture, however these vary widely among the states. For example, in January, 2014, Virginia adopted legislation to allow for FSIS-exempt on-farm poultry processors to direct-market within state lines provided they pass a state inspection with requirements and standards directly adopted from the regulations applied by USDA to large-scale poultry processors [5, 6]. Pennsylvania requires poultry processors retailing fewer than 1,000 birds per year to register with the state department of agriculture, but does not have
formal requirements or standards beyond those included in the FSIS/PPIA exemption. Growers processing between 1,000-19,999 birds/year in Pennsylvania are not covered by any federal or state regulations or policy [7]. West Virginia poultry producer-processors retailing fewer than 1,000 birds per year are required to register with the state department of agriculture in order to direct-market their products within the state, but are not subject to any other formal standards or inspection requirements. Poultry producers growing more than 1,000 birds per year in West Virginia are not allowed to market their poultry products unless they have been processed at a USDA-FSIS inspected facility [8].

Until 2010, Maryland had no formal policy for FSIS-exempt poultry processors, except that on-farm poultry processors (who were uninspected and did not have to formally register with any food safety agency) could only legally sell fewer than 20,000 birds per year at on-farm retail locations on the same property where the processing facility was located. Apart from this sole requirement, Maryland FSIS-exempt poultry producers were not required to meet any specific food safety standards (though they are instructed under the PPIA exemption to generally maintain a clean facility and sell unadulterated products), were not inspected in any capacity, and did not have to register their operation with any agency responsible for food safety policy. Only poultry products processed at an FSIS-inspected facility could be sold off-farm in Maryland, and these products were inspected and regulated by USDA, and not covered by any statewide policy.

In Maryland, the Maryland Department of Agriculture (MDA) has developed, and in 2010 implemented, a voluntary food safety inspection and training program for FSIS-exempt poultry processors. FSIS-exempt poultry processors who have not voluntarily completed the certification may only legally sell their poultry products at on-farm stands, but are otherwise
unregulated by state or federal agencies. FSIS-exempt processors who have completed the voluntary certification under the MDA’s program are permitted to sell poultry meat intrastate at farmer’s markets, to restaurants, and at other off-farm retail locations. The certification does not allow for sale to secondary retailers; all sales under MDA certification are direct-to-consumer [1].

The MDA’s certification program consists of a one-day training, a $75.00 annual registration and inspection fee, a microbial water inspection, and the inspection and approval of a written Hazard Analysis and Critical Control Point (HACCP) plan, a Standard Sanitary Operating Procedures (SSOP) plan, and written Good Manufacturing Practices (GMPs). The program also contains requirements and standards for facility infrastructure, packaging and labeling, recordkeeping, temperature for chilling, refrigeration and freezing of carcasses, and offal and wastewater disposal [1]. A scheduled annual inspection of paperwork and facilities is also included in the requirements for maintaining licensing under the program.

Interviewees discussed a wide range of issues related to these topics, and offered an array of opinions and perceptions of the MDA’s certification program, the MDA as an agency, and how regulation from the state and federal levels affects direct-market poultry producers’ ability to provide safe food and run a solvent business.

The goal of this research was to use data obtained from in-depth interviews to achieve two specific aims: 1) Describe the perspectives of Maryland direct-market poultry producers on the state and federal food safety policies that govern the statewide commercial supply chain for direct-market poultry meat products, and; 2) Characterize issues raised by participants that describe the relationships between food safety policies and microbial contamination of consumer poultry meat products in the direct-market poultry supply chain.
3.2 Methods

We conducted a series of in-depth interviews with direct-market poultry producers in Maryland to document and describe the perspectives and opinions of participants in the statewide direct-market poultry supply chain on these issues. With the exception of three participants (whose poultry processing facilities were USDA-inspected) all interviewees direct-marketed poultry processed at FSIS-exempt on-farm processing facilities.

Interview questions were designed to elicit information related to food safety policy affecting the statewide direct-market poultry supply chain. The questions were developed using several different sources of information: informal conversations with MDA employees who administer the Rabbit and Poultry On-Farm Processing Certification program and a former Maryland poultry farmer (who has since moved to another state) provided important insights. In addition, a review of the requirements and standards in the MDA’s program [1] provided a structure for directed questions about participants’ perspectives on particular aspects of the certification program.

We identified participants via publicly available commercial registries and databases, including the MDA Rabbit and Poultry On-Farm Processing Database, and several commercial self-registries that promote and advertise direct-market agricultural producers in Maryland. A complete list of the commercial registries used to identify potential participants is included as Appendix A. As a secondary strategy, we used snowball sampling [9] to identify participants whose contact information was not available through the aforementioned sources. Participants were recruited via email or phone, and offered a $20.00 cash incentive to participate. The lead author conducted all of the interviews at places convenient for the interviewees (on-farm or in a coffee shop).
Interviews were transcribed verbatim with the interviewees’ permission, then thematically coded and annotated to highlight important topics and observed patterns in the data. These coded interviews were further analyzed to assess the frequency and strength of particular themes, opinions and perspectives in accordance with standard qualitative data analysis techniques [10]. The Johns Hopkins Bloomberg School of Public Health Institutional Review Board approved this project.

3.3 Results

3.3.1 Enrollment and Recruitment

We invited 43 eligible participants to be interviewed via email. Twenty-one people expressed interest in participating, but four did not meet the inclusion criteria (two were not yet commercially active, one raised and processed only turkey and exotic waterfowl, and we were unable to follow up with the last respondent because he appears to have sold his farm and left the state between first email contact and follow-up contact via phone). One person declined to be interviewed and 21 did not respond to the invitation, so we consider them to be passive refusals. We completed interviews with 16 respondents between January, 2014 and November, 2014. The interviews lasted between 30 and 120 minutes, and averaged 75 minutes. Table 3-1 describes some of the demographics and background characteristics of the participants. Six of the 16 participants were certified to process poultry under the MDA Rabbit and Poultry On-Farm Processing program. One other participant was MDA-certified at the time of the interview in 2014, but has since allowed his certification to lapse. Another participant processed poultry at an on-farm facility that was inspected by USDA-FSIS. Another participant was a producer who takes his poultry to an MDA-certified third-party processor, and two other participants take their poultry to a USDA-certified third party
processor. The farmers we interviewed were all white, but reflected a wide spectrum of age and experience. Most (~81%) participants process their birds on the farm. Two of the three USDA-certified participants produce and direct-market but do not process poultry themselves, while the third operates an on-farm USDA-FSIS inspected poultry processing facility. The five uncertified participants were on-farm producer-processors who operate without MDA certification, and who exclusively market their products through on-farm retail venues. Most participants were at least familiar with the MDA’s program, and several had attended a training meeting for the program but elected not to follow through with certification.

3.3.2 MDA Rabbit and Poultry On-Farm Processing Certification program

While almost all participants had some familiarity with the MDA’s certification program, only 50% had completed all of the requirements for full certification. With the exception of the single USDA-FSIS inspected on-farm poultry processor, the remaining participants either used third-party processors certified by USDA or MDA, or direct-marketed their poultry to consumers from on-farm retail stands and through CSA programs which limited their regulatory oversight to the few provisions of the FSIS exemption. Though certified and uncertified participants were critical of the certification program, certified poultry producers generally expressed more favorable opinions about the program, and opined that Maryland farmers engaged in direct-market poultry were “lucky” because the MDA offered a better suite of regulations and market options for small farmers than many other states. Most of these certified participants described the program as “a step in the right direction,” and appreciated that it was designed with assistance to small farmers in mind. A minority of certified participants expressed less favorable views about the MDA’s program, but were still
grateful that the program existed, with one participant characterizing it as “a necessary pain in the ass.”

Opinions were more varied and negative towards the MDA certification program among direct-market poultry processors who had not completed the program. Several uncertified participants had attended an informational session or a training workshop for the certification program, but did not complete the certification process. There was a general impression that the program requirements were burdensome, time-consuming, and frequently irrelevant to the models and practices employed in small-scale poultry production and slaughter. Some participants also believed that the program’s $75.00 per year registration fee was too high. We also heard from these participants that the architects of the MDA program did not seem to understand the needs of small farmers and the realities (particularly the limited economic resources and the lack of spare time) inherent in running a small farm. One of the opinions repeated by several farmers was a need for greater clarity of expectations for meeting the standards to be certified under the program, particularly with regard to the HACCP plan and other paperwork requirements.

“…when you want to get through a program like this, and the people putting it together don’t understand that your time and money that you’re putting into this are significant investments for small farmers, that’s when it gets frustrating…you just can’t sit down for weeks to put together a [HACCP] plan without some clear idea of how to do it right... Not when you have a farm and a business to run.”

Some uncertified poultry farmers did not hold a particularly hostile or negative point of view about the MDA’s program, but merely saw it as an unnecessary inconvenience, since they did adequate business with on-farm sales, which do not require inspection or oversight from state or federal authorities. This difference of opinion seemed predicated primarily on location and proximity to consumer markets. Farmers located in remote areas of Maryland frequently reported that on-farm sales are not an adequate source of revenue, because there
are not enough potential customers in the immediate area to sustain their business. Farmers who are more proximal to larger consumer markets and who have been able to build and maintain a core of local customers who frequently purchase poultry and other goods from their on-farm retail operations frequently expressed that they saw no real advantage to obtaining MDA certification. All five of the uncertified on-farm producer-processors who were interviewed expressed this opinion. Conversely, all of the MDA-certified poultry farmers we interviewed expressed that they needed to be able to sell off-farm to be financially successful.

3.3.3 Frequent dissatisfaction with HACCP plans and paperwork requirements

Among both certified and uncertified processors, the paperwork requirements for obtaining certification under the MDA program were the most frequently discussed area of dissatisfaction and the largest disincentive for participation in the program. A majority of participants described the HACCP plans as unnecessarily onerous, and that the requirements and standards were unclear as applied to a small on-farm poultry processing operation. Most participants expressed that the HACCP/SSOP model for controlling and assessing food safety issues was ineffective at reducing food safety risks at the direct-market scale.

“[HACCP plans] are not effective [at reducing food safety risks]. It has become a paperwork exercise. Something everyone knows they need to have on file… I don’t think it’s accomplishing what they think it’s accomplishing.”

A frequently-expressed opinion among participants was that the adoption of the HACCP plan and paperwork-heavy model for regulating food safety at the direct-market level of the poultry supply chain was a direct import of the USDA-FSIS food safety regulations from which FSIS-exempt poultry processors are supposed to be excepted. Many participants believed that the choice to adopt a scaled-down version of the USDA-FSIS food safety model represented a lack of understanding on the part of MDA to recognize that the small-scale poultry supply
chain is fundamentally different from industrial scale poultry operations. Participants believed that effectively regulating food safety at the direct-market scale requires a different, more nuanced approach than a “one-size-fits-all” strategy.

“One of the frustrating things is that the MDA certification process, you know, they took the federal stuff we were exempt from and still made it try to apply to us.”

Many participants also believed that regulating all poultry producer-processors raising between 1-20,000 birds/year was an extension of the “one-size-fits-all” mentality, resulting in policies that are burdensome and unnecessary, particularly for direct-marketers on the smallest end of the 1-20,000 bird/year spectrum.

“The regulations get really unworkable if you’re just operating at the really, really small level. Like 100-300 rabbits, maybe 500 chickens. And it goes all the way up to 20,000! And we’re covered by the same law. And that doesn’t really make sense to me… I resent the fact that they’re trying to make all of us into this one-size-fits-all industrial model.”

A minority of participants voiced a favorable view of the HACCP/SSOP plans as a practical tool for achieving higher food safety standards at the direct-market level of poultry processing. However, almost all participants believed that a food safety strategy that was less burdensome than a traditional HACCP/SSOP plan for small processors and more efficient at achieving food safety goals was both possible and desirable. Even proponents of the HACCP/SSOP model voiced a desire for a more streamlined system that is tailored to the smaller scale. One participant who was generally in favor of the HACCP model noted:

“There’s probably a good way to combine them [HACCPs, SSOPs, GMPs] into one slick document that’s a little bit easier. They’re so similar…So maybe there’s like some way to condense all that into a few pages.”

Many participants identified the HACCP plan requirement as the main obstacle to more qualified poultry producers participating in the certification program. Many participants believed that if the presentation of the HACCP requirements were different, then
participation in the program would be less intimidating to qualified direct-market poultry processors.

“...some of the reasons people don’t go through with it is because it just seems like this big daunting thing that’s going to occupy months of your life...if there was some kind of video explaining how it was for someone to go through the process in their own words and showing what it was like and what was necessary...That would show that it’s not that scary.”

3.3.4 Preference for on-site inspection over paperwork-based inspection

Many participants voiced a preference for a food safety regulatory strategy that focused more on on-site inspection and less on paperwork. These farmers believed that paperwork inspections did little if anything to reduce the real risks of consumer exposure to contaminated poultry products. By their estimation, paperwork could be easily fabricated by the farmer, and did little to ensure that best practices for food safety risk reduction were consistently in use. Most participants expressed a favorable view of more rigorous on-site inspections and performance-based measures in regulating food safety in direct-market poultry retail, as captured in the following quote from one participant.

“I have no problem at all with an inspection, with a guy coming around here. We’re very proud of our processing facility, and we’d show it to anybody.”

Performance-based measures mentioned by participants focused on establishing acceptable cutoffs for microbial contamination of poultry products and testing certified poultry farmers for compliance with regular microbial sampling and testing of consumer poultry meat products.

3.3.5 General perspectives on government, regulation and MDA

Among participants who were more novice farmers, or who had a background in another occupation, the general opinions toward MDA, the certification program, and broader ideas of regulation by the government in general were consistently more favorable, and a greater number of these participants had completed the MDA certification program. Among highly
experienced farmers who did not have work experience in another professional field, the opinions on those same topics were generally more negative, and viewed the MDA and any regulatory strategy affecting small farms with inherent mistrust. This pattern was observed in the primary interview data collected, and was also commented on by many participants.

“I think there’s a culture of some farmers who are extremely progressive and open to a lot of new ideas. They’re younger and they are the people that are generally newer to this business. There are also some really old-time farmers who are totally dead-set against the program and don’t trust [the MDA’s] intention.”

Negative views towards the federal and state governments were fairly common among many participants. These perspectives were not limited to older, highly experienced farmers, though this group did consistently espouse anti-government sentiments. Even among participants who had completed the MDA program, negative opinions about the role of government generally in the lives and businesses of small farmers were frequently expressed. One MDA-certified participant who had been commercially farming for three years conveyed a widely-held general sentiment:

“…the government’s the government. I’m in no way pro-MDA or pro-government. I’m associated with them because I have to be.”

Other participants held the MDA in higher regard than federal government agencies and other state agencies that regulate small Maryland farms. Particular individuals within the agency who have been regarded as helpful were singled out as exceptions to a more general rule that government does not have a constructive role in promoting best practices or economic prosperity for small farms.

“Everybody hates Annapolis…the legislature, but not too many people actually have too much of a problem with MDA.”

Somewhat paradoxically, many of the same participants who had a negative view about the role of government in direct-market agriculture expressed a desire for some regulatory authority (generally referring to MDA) to create effective standards for quality and safety for
direct-market Maryland poultry. This perspective was usually mentioned in the context of wanting to protect the supply chain from potential “bad actors”. These bad actors are hypothetical FSIS-exempt poultry marketers who would not use responsible methods or best practices to grow and process their birds and who would introduce higher-risk products that could sicken consumers and cause a local outbreak of infectious disease. The concern was that such an outbreak event would damage the reputation of the direct-market poultry supply chain generally, and that this would hurt the businesses and reflect poorly on small poultry farmers who were using best practices. Participants anecdotally related stories of witnessing or hearing about practices they considered to be risky or irresponsible from a food safety perspective in the direct-market agriculture business. However, almost all participants believed that potential “bad actors” represented a very small minority of the direct-market poultry and agriculture businesses in Maryland.

“I used to be like “people should be able to eat whatever they want!”, but I’ve seen some things. And I know there’s some people out there who you can’t trust necessarily to do a good enough job. And I think it’s good to have some rules and standards that you can go back to, and someone to enforce them.”

Most of the participants who expressed this opinion, however, did not think that the current MDA certification process was adequate to protect the supply chain from bad actors, further questioning the paperwork-centered route to regulating small-scale poultry operations.

3.3.6 Ways to promote best practices for food safety in the direct-market supply chain

Participants were asked how to improve the current regulatory infrastructure that affects Maryland direct-market poultry farmers. Many common responses emerged in response to this question. Most commonly, the desire for more streamlined and simplified paperwork certification requirements, or for more guidance about how to properly complete the HACCP/SSOP/GMP paperwork more efficiently.
Including hands-on instruction with the MDA certification training so that novice poultry processors could learn how to process safely and within the regulatory guidelines was another common request. Most participants felt the current training strategy was adequate for showing experienced poultry processors how to process legally, but that the same strategy was not adequate to train an inexperienced poultry processor how to slaughter and process safely from a food safety perspective. Some participants voiced the concern that novice processors who did not yet understand or consistently use best practices would be legally certified to sell their products in the same supply chain as the marketers consistently using best food safety practices, increasing the risk for collateral damage to the collective reputation of the Maryland direct-market poultry supply chain. Participants also believed that offering a state-sanctioned hands-on training program would help more new poultry farmers to enter and grow the direct-to-consumer poultry market, and provide an incentive to complete the certification process.

Another commonly-voiced opinion was that increased communication between Maryland poultry farmers operating at the direct-market could be used to promote and share ideas for best practices and new concepts for protecting food safety. Some participants believed that the process of growing this kind of network could be formalized by creating a regional or statewide farmer-to-farmer network to achieve a variety of outcomes related to food safety. One participant very clearly articulated the potential benefits of this kind of network, and outlined a role for state regulatory agencies to help in facilitating this outcome:

“...farmers need to be looking at what other farms are doing, sharing ideas, and actually calling out bad actors or people who aren’t doing it right...farmers are so willing to learn from and teach each other...you could set up a system where farmers can be mentoring each other...there could be a role for MDA in helping to put together that peer-to-peer network or help facilitate that training.”
3.4 Discussion

3.4.1 Applications for policy in Maryland and other states

From the perspective of many of these small farmers, regulation and policy in Maryland has not been effective at evaluating or mitigating food safety risks in the direct market supply chain because of a lack of understanding on the part of policymakers of the structural and tangible differences between industrial-scale and small-scale poultry production. Many participants also believed that the existing regulation and policy handicaps the ability of Maryland’s direct-market agriculture supply chain to thrive financially. The degree to which this sentiment is accurate is perhaps arguable. A more important and less debatable issue is that this perception among small-scale farmers alienates them from the efforts of policymaking agencies regulating food safety in small agricultural markets. This in turn makes regulatory issues such as implementation, enforcement, and compliance more difficult and challenging to address, and undermines the effectiveness of any policy-based strategy to mitigate food safety risks in this supply chain. These analyses offer a foundation for more well-informed communication between policymakers tasked with regulating small agricultural markets and direct-to-consumer commercial poultry livestock marketers in Maryland. Policymakers crafting regulation in the direct-market supply chain (particularly voluntary and/or incentivized regulation such as the MDA on-farm processing certification) can potentially increase compliance in the target population and craft more tailored food safety protections by incorporating the perspectives and opinions voiced in these interviews.

The thematic content reflecting on the MDA, the Rabbit and Poultry On-Farm Processing Certification program, and the relationship between small farmers, state and federal regulatory agencies and the government also contains valuable analysis for policymakers.
Understanding what aspects of governance are appealing, off-putting, appalling, or confusing to this population can be critical in crafting and implementing regulation that is responsive to the needs and realities of small agricultural operations.

Direct-market agriculture constitutes a growing and increasingly important (and, for that reason, increasingly necessary to regulate) aspect of the food system in Maryland and many other states. With issues such as regulation and establishment of standards for small-scale poultry processing and retail left to individual states to manage and regulate, the efforts of the MDA can provide a template and an object lesson for other states in the Mid-Atlantic region and the US in designing and implementing food safety regulatory programs for their direct-market agriculture systems, particularly for poultry production. The observations and data from this research in all of the abovementioned categories can be used to enhance not only Maryland’s regulatory strategies for direct-market poultry and agriculture, but potentially also those of many other states.

3.4.2 Limitations and areas for further research

The findings from this study are limited in some regards. While a sample size of 16 may seem like a low number, a broader survey of the Maryland direct-market poultry supply chain has identified fewer than 70 active participants in the direct-market poultry supply chain who met the inclusion criteria for this study. However, while this sample may be fairly representative of Maryland’s direct-market poultry supply chain, it is reasonable to assume that some issues related to both food safety risks and regulation may considerably different in other regions of the US. Issues directly related to MDA may not apply to regulatory paradigms in other states, which set up their own independent regulatory strategies for direct-market poultry, if they have any formal policies at all. However, it is possible that
there may be a regional effect in the generalizability of these findings, wherein the issues and perceptions of those issues in comparable populations may be more similar in regions proximate to Maryland than in those more geographically distant. Further investigation into these topics should include states such as Delaware, Virginia, Pennsylvania and West Virginia to establish the validity of such a regional effect.

There may also be some response bias concerns in terms of only sampling among participants who volunteered to be interviewed. It is possible that such a response bias occurred, however, given that an estimated 20-25% of the extant population of direct-market poultry producers were actually sampled as part of this study, we feel confident that these findings are at least representative of a large portion of the overall population.

However, further research should also be conducted to establish the extent of the validity of these findings within Maryland, and to build upon the research foundation that has been established here.

3.5 Acknowledgments

I would like to acknowledge Dr. Shannon Frattaroli, Dr. David Love and Dr. Meghan Davis for their comments, input and proofreading of this manuscript. Dr. Frattaroli also contributed to the analysis and reporting of the data. Deanna Baldwin from MDA also provided input in helping to craft the lines of inquiry used in the interview guide.

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3.6 References


[2] United States Code of Federal Regulations Title 9, Chapter III, Subtitle A, Section 381.1


Table 3-1: Demographics and Background Characteristics of Study Participants

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<tr>
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Chapter Four

Manuscript 3:

“Clean In, Clean Out”: An Integrative Methods Investigation into Risk Management Strategies for Control of Antimicrobial-Resistant and Susceptible Microbial Foodborne Pathogens in the Maryland Direct-Market Broiler Poultry Supply Chain
Abstract: The objective of this study was to use integrative, mixed methods to describe the models and practices applied to risk management strategies for controlling microbial contamination of broiler poultry meat products in the direct-to-consumer supply chain in Maryland. Additionally, this study aimed to more fully describe the variety of commercial direct-market poultry production operations in Maryland along characteristics that may be relevant to microbial food safety in this supply chain. Between January 2014 and November 2014, I conducted semi-structured, in-depth interviews with a convenience sample of 16 commercial poultry producers and direct-marketing operators in Maryland. Participants described the practices, process controls, and structural aspects of their production and processing infrastructure that they considered important to maintaining food safety in their operations. These data were used to develop a survey questionnaire that was administered more broadly among direct-market poultry producers in the state. This survey tool was used to gather quantitative data on the distribution of a variety of factors related to small-scale poultry production and processing that were identified as relevant to microbial food safety outcomes during in-depth interviews. Between October 2014 and March 2015, I surveyed 40 Maryland commercial poultry production and direct-marketing operations. By analyzing responses to the survey tool from a majority of the statewide population of direct-market poultry producers, we were able to describe the landscape of the statewide supply chain, focusing on characteristics related to risk management strategies applied to microbial food safety in direct-market poultry products.
4.1 Introduction

4.1.1 Direct-market agriculture in the US

Direct-market retail of agricultural products has been steadily increasing in the US over the last two decades [1]. Direct-market participants are responding to an increased demand nationwide for local, sustainably-produced agricultural products [2]. While livestock farmers accounted for only 9.3% of direct-market participants in 2007, nationwide direct-market sales totaled $377 million in that same year, making animal products the highest in gross sales among all agricultural product categories [3].

4.1.2 Food safety risk management in direct-market poultry systems

Despite the growth of direct-market agriculture and poultry livestock supply chains in the domestic food supply, few studies have included any evaluations of small-scale poultry operations from a food safety or risk management perspective in the United States. One study by Melendez et al. analyzed environmental samples from two poultry production facilities in Arkansas that kept free-ranging poultry livestock, and found low but detectable prevalence of viable Salmonella isolates that were resistant to multiple classes of antibiotics, including sulfisoxazole and novobiocin, on two farms that had no history of antibiotic usage [4]. The study by Melendez et al. also sampled for Salmonella on retail meat samples purchased at a local grocery store and a local processing plant from poultry products labeled as “pasture-raised,” and demonstrated that around 30% of samples purchased from a single local health food store and a local poultry processing facility were positive for Salmonella and that approximately 10% of these isolates were resistant to three classes of antimicrobials. No isolates recovered in this study were resistant to four or more classes of antimicrobials [4]. While this research indicates the potential for drug-resistant pathogens to colonize and
survive on the small poultry farm environment, this study contained several structural limitations that curtail the interpretations and generalizability of the findings. Primarily, the very low number of farms participating in the study is not a large enough sample to justify generalizability of the data to the direct-market industry. Also, the authors provided little information regarding the two participating farms, beyond the criteria for raising of poultry in a pastured model and self-reporting of no usage of antibiotics in their poultry production operation. The study did not report whether these farms raise other livestock, their geographic proximity to industrial scale poultry or livestock production, or on-farm practices, inputs or characteristic features of these operations that potentially could contribute to the prevalence of drug-resistant *Salmonella* sp. in the farm environment. In addition, the retail meat samples analyzed in this study were not purchased from the two participating farms, but from two third-party retailers (a grocery store and a commercial poultry slaughterhouse), not allowing the poultry meat samples to be matched to environmental samples from the participating farms. All of the retail meat products sampled in this study were not purchased through a statewide direct-market supply chain, but rather through a niche of the intermediated supply chain, which involves third-party meat processors as well as retailers, and is distinct in many ways from the direct-market supply chain for these products. Hence, to the best of our knowledge, the study described here is the only existing research of its kind that includes evaluation of commercial small-scale poultry production in the US from a microbial food safety perspective.

A handful of other studies have evaluated biosecurity and risk of animal disease transmission in non-commercial flocks of poultry kept in the US. One such study evaluated Maryland’s population of backyard, noncommercial poultry producers, a model in which poultry are kept as a hobby, or to provide meat and eggs exclusively to the family who own the
livestock. This research analyzed responses to a survey questionnaire from 41 participants who kept small, non-commercial poultry flocks in the state. Respondents reported a median flock size of 38, and the researchers’ analysis demonstrated high variability in biosecurity practices among participants [5]. Another study from Colorado using a similar survey questionnaire tool gathered data on backyard, non-commercial poultry production in that state, and demonstrated similar results [6]. Their findings determined that minimal and variable biosecurity practices in backyard non-commercial poultry production, such as shared human contact between backyard and commercial poultry flocks, created an environment with potentially high risk of transmission of avian diseases. However, the research on backyard, non-commercial poultry operations does not necessarily apply to the models, practices, and issues faced by small, direct-market commercial poultry producers. In addition, none of the research on backyard non-commercial poultry production focused on microbial food safety of consumer poultry meat products, as most backyard flocks are kept for eggs, not meat, and because there inherently is no commercial consumer market for backyard poultry meat products as these livestock are grown for private consumption by the family and not for sale.

Outside the US, there has also been only limited public health research into factors affecting food safety risks in small-scale poultry production and processing. A study from Northern Thailand used an integrative, mixed-methods strategy to characterize the landscape of small-scale, backyard poultry farming in rural communities in the Chiang Mai province [7]. The study combined and analyzed data from survey questionnaires, focus groups, and in-depth interviews with small poultry farmers on their perceptions of food safety risks, policy and regulation, and other relevant issues. These data were used in conjunction with on-site microbial sampling of small poultry slaughter and processing operations to illuminate the
complex, interactive factors affecting food safety in small-scale poultry production and processing in this region. A stakeholder-informed conceptual risk framework for identifying and improving food safety issues in this environment was developed, and included recommendations for all stakeholder groups (farmers, consumers, policymakers, veterinarians, public health researchers) to improve food safety outcomes in this supply chain.

In Finland, a recent study surveyed residents keeping backyard poultry flocks as a non-commercial operation [8]. The same research also examined data on post-mortem analyses of carcasses from non-commercial laying hens raised in backyard flocks. The study showed that most of these flocks were very small (<50 birds), had relatively low rates (compared to industrial-scale poultry flocks) of disease and mortality, and frequently co-mingled with pets, wild animals and other livestock animals. The findings from the post-mortem analyses indicated that Marek’s Disease (27%) and colibacillosis (17%) were the most commonly observed poultry diseases. The research concluded that the small size, low disease rate, and lack of close connection with commercial poultry flocks indicated that the risks posed to commercial poultry flocks were low [8]. A similar study used a survey tool to gather data from people keeping backyard, non-commercial flocks of laying hens in British Columbia, Canada, and demonstrated similar results regarding flock size and the potential for disease transmission between commercial poultry operations and non-commercial backyard poultry flocks [9]. However, as with the studies on backyard poultry in the US, the findings from these studies and other comparable research on small, non-commercial poultry production do not necessarily apply to the models, practices, and issues faced by small, direct-market commercial poultry producers.
The limited existing research, combined with the growth and expansion of the direct-market agriculture in the US, has left an important gap in the knowledge base on factors potentially affecting food safety risks in the direct-market food supply chain environment. This research was carried out to partially fill that knowledge gap by focusing on the supply chain for a category of consumer products known to be important in microbial food safety: broiler poultry meat. The specific aims of this study were to use integrative methods to describe and evaluate the practices and characteristics of Maryland direct-market poultry production and processing that are used to control microbial food safety risks, focusing particularly on risks associated with contamination of consumer products with antibiotic-resistant strains of foodborne bacterial pathogens. By collecting and analyzing two kinds of data, in the form of in-depth interviews with a convenience sample of Maryland direct-market poultry farmers and a survey questionnaire administered to a larger sample of poultry producers in the statewide supply chain, this research used integrative methods to address an important knowledge gap. Specifically, this study (1) describes the concepts, practices, and perspectives informing microbial food safety risk management strategies employed by commercial participants in the Maryland direct-market broiler poultry supply chain, focusing particularly on risk reduction strategies for contamination of consumer products with antibiotic-resistant strains of microbial foodborne pathogens; and (2) describes the variety and distribution of poultry production models, slaughter and processing practices, on-farm inputs, and other key characteristics of small-scale poultry farming potentially relevant to these microbial food safety outcomes in the statewide supply chain for direct-market poultry meat products.
4.2 Methods

4.2.1 Mixed-methods sequential exploratory strategy and study design

In order to document and describe the concepts, practices, and perspectives informing food safety risk management strategies applied in Maryland small-scale poultry production and processing, we employed a mixed-methods sequential exploratory strategy [10]. Under this strategy, an initial phase of qualitative research is performed and the data is analyzed. The qualitative analysis (stage 1) is followed by a quantitative research and analysis in the same environment or population (stage 2). The process of this research strategy is to use quantitative methods to provide a more refined description of observations from qualitative data, with the purpose of exploring a relatively unexplained phenomenon in a novel environment, rather than to describe and explain specific causal relationships associated with known outcomes [10]. Using this framework, we first conducted a series of in-depth interviews with a convenience sample of 16 direct-market poultry producers. The questions were designed to elicit information and responses on the risk management strategies employed by participants to control contamination of their facilities, livestock, and poultry meat products with antibiotic-susceptible and resistant foodborne pathogens. Interviews were transcribed verbatim with the interviewees’ permission, then coded and annotated to highlight important topics and observed patterns in the qualitative data. These coded interviews were further analyzed to assess the frequency and strength of particular themes, opinions and perspectives in accordance with standard qualitative data analysis techniques [10]. Data from these 16 interviews were subsequently analyzed to identify key aspects of small-scale poultry production and processing considered to be important to food safety risk management by commercial operators in Maryland. We used this analysis to develop a survey questionnaire tool that we administered to a broader sample of Maryland direct-
market poultry producers. The questions in the survey tool focused on descriptive characteristics and workplace practices of small-scale poultry production and processing models identified as relevant to food safety risk management by participants during in-depth interviews. These factors included: scale and size of production and processing operations; professional experience of producers and processors; antimicrobial usage in poultry production; maintaining multiple animal species in close or overlapping proximity; sanitary practices during slaughter and processing; poultry production practices; use on on-farm and third-party processing facilities; and sourcing of livestock. Other information gathered using the survey questionnaire included county-level location data and processor certification status under MDA or USDA.

4.2.2 Identification and recruitment of participants

We identified participants for the in-depth interview via publicly available commercial registries and documents, including the MDA Rabbit and Poultry On-Farm Processing Database, and several commercial self-registries that promote and advertise direct-market agricultural producers in Maryland. A complete list of the commercial registries used to identify potential participants is included as Appendix A. As a secondary strategy, we used snowball sampling [11] to identify participants whose contact information was not available through the aforementioned sources. Participants were recruited via email or phone contact, and offered a $20.00 cash incentive to participate. The lead author conducted all of the interviews at places convenient for the interviewees (on-farm or in a coffee shop).

To recruit participants for the survey questionnaire, we returned to the contact information of eligible Maryland direct-market poultry producers compiled from the MDA’s database and the other commercial registries and systematically attempted to contact all eligible poultry farmers
for whom contact information could be obtained. This study population identification strategy deliberately excludes the backyard, non-commercial poultry operations, which are not listed in the commercial registries used to compile this assessment of the statewide population of direct-market poultry producers. Inclusion criteria were that the respondent be commercially active in the Maryland direct-market broiler poultry supply chain at the time of the survey; within these parameters, there were no exclusion criteria. Telephone calls were placed to the business lines listed in the databases used to identify participants as a method of initial contact and recruitment. We offered a $10.00 cash incentive to eligible poultry farmers to complete the survey. The lead author administered all of the surveys in-person with the respondents at their home or place of business (which were generally the same location).

The Johns Hopkins Bloomberg School of Public Health Institutional Review Board approved this project.

4.3 Qualitative Results: In-Depth Interviews

4.3.1 Enrollment and recruitment

We invited 43 eligible participants to be interviewed via email requests. Twenty-one people responded, and one declined to be interviewed; these 22 (51%) constitute passive refusals. Of the remaining 21, four expressed interest but did not meet the inclusion criteria: two were not yet commercially active, one raised and processed only turkey and exotic waterfowl. We were unable to follow up with the last respondent because he appears to have sold his farm and left the state in the interim between first email contact and follow-up contact via phone. Hence, we completed in-depth interviews with 16 respondents between January 2014 and November 2014. The interviews lasted between 30 and 120 minutes, and averaged 75 minutes.
4.3.2 Concepts, practices, and perspectives informing risk management strategies

Participants were asked during in-depth interviews to describe the aspects of their on-farm poultry production and processing models (where applicable) as well as the workplace practices that they consider important to controlling food safety risks in their operation. These characteristics and practices included: rate and annual volume of poultry production; scale, speed and practices of poultry processing; professional experience of producers and processors; antimicrobial usage in poultry production; maintaining multiple animal species on the same property; sanitary and microbial disinfection practices during slaughter and processing; pastured poultry production practices; use on on-farm and third-party processing facilities; and sourcing of livestock. These issues are discussed in the sections below in greater detail and context.

4.3.3 Volume and rate of poultry production

Participants described two multiplicative factors used to determine the total annual volume of poultry production for a small-scale operation: the number of birds in a typical flock, and the number of flocks raised, slaughtered and sold each year. The size and the frequency of flocks of broiler poultry raised by small-scale, direct-market farmers are both carefully chosen quantities. The size of the flock is targeted to meet, but not exceed, three distinct but interrelated capacities of the poultry operation: the daily processing capacity of the poultry slaughter facility in use (with slightly different considerations for operations using on-farm versus third-party facilities); the available capacity in cold storage (typically freezer space); and the expected capacity and rate of poultry sales to consumers (with consideration for additional consumption by the farmer and family members). Efficiency of inputs such as feed costs and a profitable return on investment depends on selecting the optimal flock size to maintain for each unique operation. The circumstances factoring into the choices of how
many flocks per year to raise are based on other considerations, most closely related to the capacities used for determining flock size selection. Similar to flock size, expected sales rate is a primary consideration in deciding how many flocks to raise in a year; participants voiced a general concern over losing money by raising more birds than they can sell to their customer base. Other considerations for how many birds to raise in a year included the farmer’s anticipated profit margin for their poultry products. Their products’ price point balances with the resource needs, including time, financial overhead, physical labor and other resources. Participants use this rough calculus to determine how much of their diversified operation to invest in broiler poultry production; most described the decisions of how many birds to raise in a flock and over a season as a “moving target” that may change frequently year to year, or even within a single season. The scale of on-farm poultry production and processing was cited by participants as an important factor affecting microbial food safety outcomes in several interrelated ways, described below in greater detail.

4.3.4 Poultry livestock health in small-scale production

One consensus opinion was that disease control and low mortality rates are relatively easy to maintain in broiler poultry raised in small-scale flocks by using a relatively simple set of practices, modified to the particulars of each operation’s business goals and resource limitations. The descriptions of best practices for poultry livestock health were often similar, but were never identical, and sometimes varied substantially among participants. More details on these practices are included in the sections below; none of the practices used by participants included prophylactic pharmaceutical antibiotic inputs, which participants universally deemed unnecessary in their model. Participants believed that avoiding or using limited antibiotic inputs in their poultry or other livestock production decreased the
likelihood of highly-drug-resistant pathogens contaminating their operations and their poultry products.

4.3.5 Antimicrobial usage in poultry livestock production

Antimicrobial resistance in foodborne pathogens was considered to be a serious problem by almost every participant. One participant stated that he did not believe that antibiotic usage in industrial livestock production was a public health issue; he attributed any public health issues with antibiotic resistance to mismanagement of prescription drugs in the healthcare system. No participants, including the individual with this outlier opinion, reported using prophylactic or growth-promoting antibiotics, though two participants reported occasionally using therapeutic antibiotics to treat sick animals (N.B. one only used therapeutic antibiotics for turkey, not the target broiler poultry.) Almost all participants cited larger public health risks associated with overuse and misuse of antibiotics as one reason for not using antibiotics in their production model.

I would never use those practices. I think it’s bad for the animals, it’s bad for the environment, it’s bad for humanity, and unless we can come up with a lot of new medicines…. we’re headed for a lot of big problems with antibiotic resistance worldwide.

Participants in this supply chain opt for a poultry production model that necessitates a minimum of pharmaceutical antimicrobial inputs by minimizing livestock disease. However, alternative strategies for livestock disease management are required for small poultry farmers trying to avoid antibiotic inputs. Participants used a range of practices that included: active monitoring for disease; culling of weak, sick or infected stock; quarantining of suspected sick livestock (and also newly arrived animals) before re-introduction to the general stock; and selective sourcing for healthy livestock.
4.3.6 Maintaining diversified livestock species

Direct-market poultry farms are almost never exclusively engaged in poultry production. Instead, farmers opt to raise small flocks of broiler poultry among a variety of other livestock species and agricultural products. None of the interview subjects exclusively raised broiler poultry or sold poultry products, but instead incorporated small-scale poultry production into an integrated system of diverse production models for several species of livestock and varieties of other agricultural products. While this was mostly cited as an economic necessity, a majority of participants also identified their system of integrated livestock and land management as a bulwark against infectious disease risk issues, particularly those issues associated with drug-resistance in foodborne pathogens.

“I think we are kind of insulated [from antibiotic-resistant bacteria]...what it comes back to is the cleanliness, and the multi-speciation of our farm. The multi-speciation is huge, and we’ve gotten to the point in the industry where we use monocultures [that] don’t exist in nature...And [on our farm] we stack enterprises. I’m talking cattle, pigs...we’re mixing herbivores, omnivores, and then letting the ground rest, rejuvenate. And letting the sun sanitize that pasture. And that’s after the birds have gone through it and cleaned up after the cattle. And what that does is confuse pathogens, and you get that natural selection [against drug-resistant bacteria]...you can’t argue with nature!”

Most participants believed that keeping multiple species of livestock as part of an integrated land management system decreased the likelihood of creating a specific environmental niche that could harbor antimicrobial-resistant bacteria or allow any specific foodborne pathogen in particular to gain a foothold and thrive under selective pressure. This was offered as a point of comparison with industrial-scale poultry farms, which are typically homogenous, single-species environments. Participants viewed this type of “monoculture” production as more likely to generate issues with infectious disease among poultry livestock (which would in turn necessitate greater on-farm use of antimicrobial inputs). Participants perceived that the monoculture poultry production model contributed to increased risks of higher concentrations of microbial pathogens accumulating in the farm environment and ultimately,
increased risk of livestock illness, necessity of antimicrobial inputs, and ultimately increased risk of contamination of consumer products with both drug-susceptible and drug-resistant strains of foodborne bacterial pathogens.

4.3.7 Pastured poultry production systems

All but three participants used a “pastured poultry” production model, in which small flocks of poultry were kept in mobile housing and rotated through different paddocks of open grazing pasture. Birds forage and were frequently also fed scraps of produce, but were provided with a grain-based feed. Perceptions among participants using pasture-based models varied as to what practices they used in terms of how much space per bird should be allotted in each paddock, how frequently housing should be moved, and how these factors could potentially affect food safety outcomes.

Most participants claimed that their mobile poultry housing was moved daily (sometimes even more frequently) in an effort to keep poultry manure from accumulating in one particular area of pasture as well as to separate the livestock from their feces and waste. However, some participants mentioned that they only moved their mobile housing on a weekly basis, and two farmers said they only moved their poultry paddocks monthly. All participants, including those who did not use mobile poultry housing, believed their system was adequate to optimal for maintaining animal health and contributed to the paradigm informing lower microbial food safety risks for their poultry meat products.

Participants also expressed a variety of opinions regarding the amount of space required to keep poultry healthy and animal disease to a minimum. A frequently-expressed opinion was that not everyone practicing pastured poultry as a production model held the same
perspectives about best practices as related to control of infectious disease in poultry livestock, and reducing or eliminating the need for antimicrobial inputs.

“You can definitely keep less than fifty birds in a confinement situation [with mobile housing] that is every bit as bad as how 100,000 birds are kept in confinement indoors. And I’ve seen it done with other small farmers. And then you’re going to have the same problems with your livestock unless you use drugs [prophylactic antibiotics] as part of your system.”

However, there was no precise consensus about how much space was needed per animal. During on-farm visits, participants described and visual confirmation supported evidence that flocks were as small as 16 birds kept in an 8x10 foot movable pen and flocks were as large as 400 kept in a 1/10th acre area of pasture fenced-off with electrified netting that rotated to a new location on a weekly basis. Participants also described frequently changing and evolving their poultry housing model to improve a wide variety of outcomes (many related to animal health and disease control) and to accommodate different quantities of poultry livestock at different times. Many participants kept a greater quantity of birds in the summer months, and some participants seasonally raise turkeys between summer and late fall. Turkeys raised by participants were also kept in mobile pasture housing and were incorporated in a rotating system (though never co-mingling different species’ flocks) with pastured broiler poultry.

4.3.8 Slaughtering and processing small flocks of poultry by hand

Participants emphasized the importance of scale of poultry production and microbial food safety extensively in the context of on-farm poultry slaughter and processing. On-farm poultry processing is characterized by hand work. The process itself involves some variation on an ordered sequence of killing, bleeding, scalding, defeathering, eviscerating and (sometimes) cutting/parting, rinsing and chilling small flocks of poultry by hand in a dedicated on-farm slaughter facility. Hand work is only feasible for processing small flocks
of poultry. A higher ratio of workers : birds than would be typical in a larger, mechanized facility, combined with slow speed and manual labor inherent in these tasks, were factors that participants to exercise a high level of quality control during slaughter and processing. These factors informed the dual mechanisms of (1) accident reduction on the processing line, and (2) early detection and remediation of cross-contamination issues for equipment or carcasses that comprise the basis of microbial food safety risk management for on-farm poultry processors.

“[Processing by hand] I’m able to examine this animal personally, you know, examine the entrails…we are able to be really very thorough [with our inspection].”

Participants provided examples of this type of risk issues that are quickly identified and remediated under this system, which included: introduction of recognizably ill or infected livestock into the processing environment; visible contamination of poultry carcasses; accidental cuts to the intestines or gall bladder; accidental contact of viscera or fecal matter with knives or contact surfaces; fecal or blood contamination of chill water, and remnant pin feathers clinging to carcasses.

4.3.9 On-farm poultry processing practices

Apart from issues directly related to scale, such as hand work, participants who used on-farm poultry processing models mentioned several practices that they believed informed food safety risk management strategies in their operations. Owner/operators, other part-time or full-time farm employees, skilled day-laborers, and volunteers all may participate in on-farm poultry processing at different facilities. Some participants believed that allowing unskilled volunteers was “irresponsible to your customers,” as one participant opined. However, more participants mentioned that they would always accept volunteers, and did not see this as an increased risk to food safety. Each of the 13 owner-operators of on-farm processing facilities
mentioned that he or she personally participated in all poultry slaughter and processing. One food safety control mentioned by every participant who processed poultry on-farm was timely chilling and freezing of poultry carcasses immediately after slaughter and processing. Participants mentioned that practices such as: using adequately large chill tanks, regularly restocking chill tank water with fresh ice, changing out dirty chill tank water, and monitoring temperature with a probe thermometer, were necessary aspects of chilling poultry carcasses down quickly and to a sufficiently low temperature. Participants made a direct connection between temperature control at this critical point and risk management strategies for controlling and reducing microbial contamination of their poultry products. Because of the structures inherent in small-scale poultry production and direct-market agriculture, by necessity most meat products marketed through this supply chain in Maryland (and elsewhere in the US) are sold frozen. Unlike industrial-scale poultry processing plants, which generally operate every day, most small poultry producers will only slaughter a flock of birds once every couple of weeks. During each processing event, farmers will slaughter sufficient birds to sell that batch of poultry products for the period of time until the next flock of birds are grown to market weight and ready to be slaughtered and sold. Because of obvious concerns about product spoilage, poultry products that are not sold soon after being processed are frozen after chilling and sold to consumers as a frozen product that has never thawed during storage or distribution. Outdoor poultry production is also generally a seasonal farm activity in temperate Maryland, which typically has winter months that are too cold and wet to raise broiler poultry in this method. To keep a steady supply of poultry meat throughout as much of the winter as possible, many direct-marketers will sell products that were processed or frozen during the last processing event of the year (typically November) until the first processing event of the calendar year (typically April or May) or until they sell
out of frozen products. The typical length of time between processing and sale of frozen poultry products estimated by participants can be highly variable, from a few weeks to more than three months, even within a single operation. About one-third of participants mentioned that they will refrigerate a small number of whole poultry carcasses for consumers who are aware of the slaughter and processing schedule, and who will arrive on processing days to purchase fresh, non-frozen poultry products from participants’ on-farm retail locations. However, among the participants who sold fresh poultry on-farm, all mentioned that the number and production weight of fresh poultry sales were substantially less than the number and production weight of frozen poultry items typically sold.

Depending on the operation, participants estimated selling between 75-100% of their poultry meat products frozen. While post-slaughter carcass chilling was frequently observed as an important critical control point for food safety risks, participants did not mention product freezing, or highlight any differences between fresh and frozen poultry products for important food safety risk issues.

Many of the other practices mentioned by on-farm processors that they perceived as integral to their risk management strategies related to sanitation and disinfection of on-farm processing facilities. Participants held a wide variety of perspectives on what constituted “best practices” to achieve high standards for food safety protection in small-scale poultry processing. Some participants would clean down their entire operation mid-run after processing a few dozen birds, while others would only clean before and after processing and entire flock of over 100 birds. Some participants exclusively used combinations of different chemical disinfectants, including bleach solutions; other participants specifically excluded bleach-based chemical disinfectants from their sanitization regimes. Two participants used no chemical disinfectants at all in their operations, relying instead on physical processes such
as sanitizing equipment with boiling water and by keeping all infrastructure outside for days or weeks between slaughter events, exposed to UV sunlight. Other disinfection practices mentioned included using chemical disinfectants such as organic acids, biodegradable soaps, peroxides, and salt water. Most participants reported using multiple cleaning agents in combination; a wide variety of different approaches to microbial food safety risk management through facility disinfection and sanitization practices were described.

4.4 Quantitative Results: Survey Questionnaire

4.4.1 Enrollment and Recruitment

To recruit participants for the survey questionnaire, we returned to the contact information of eligible Maryland direct-market poultry producers compiled from the MDA’s database and the other commercial registries. We systematically attempted to contact all eligible poultry farmers for whom contact information could be obtained. Between October 2014 and March 2015 we identified and attempted to contact 93 potentially eligible participants using this system. Telephone calls were placed to the business contact lines listed in the databases from which participants were identified. Responses for the questionnaire survey were obtained from 77/93 (82.8%) of commercial operators; 16 potentially eligible participants identified using this system did not respond to two separate messages left on business phone voicemails. Having no further information about these 16 individuals, we consider them passive refusals, though it was ambiguous in some cases whether the farms listed in the databases were still in business. Sixteen of 77 (20.8%) respondents listed in one of the databases informed us at initial contact that their operation was currently out of business in the state of Maryland (some farmers reported that they had moved to other states). Another 11/77 (14.3%) respondents reported at initial contact that they were still
involved in direct-market agriculture in Maryland, but were no longer marketing poultry meat products. From the remaining 50 eligible participants, 4/50 (8.0%) declined to participate in the study, all citing privacy concerns. Six more participants were contacted and expressed interest in completing the survey, but were not able to schedule a time to participate before the close of the recruitment window. Including the passive refusals, 40/66 (60.6%) of eligible poultry farmers in Maryland identified through our recruitment process were enrolled and participated in the study. Fifteen of the original 16 participants in the in-depth interview portion of this study also participated in the survey. We made contact with the single interview participant who did not complete the survey; this participant informed us that he closed his farm business since the time of the interview, and no longer fit the inclusion criteria for the study. Though a small number of eligible poultry farms (particularly those who started their poultry business more recently) may not have been included in our estimation of the study population, we are confident that the compiled contact information assembled through the various databases of Maryland direct-market poultry producers is highly representative of the extant population of commercial participants in the statewide supply chain. This assumption was frequently checked by asking all participants if they knew of any other direct-market poultry producers in their network who would qualify to participate in this study. Although respondents provided seven potential participants to consider to interview, no participants were identified via this snowball sampling strategy who had not been previously identified through one of the databases in Appendix A.

4.4.2 Demographics and background information

Responses to the survey questionnaire were recorded and analyzed. Demographic information on the 40 respondents is reported in Table 4-1. All participants were white, and a majority (60%) were women. Profession experience varied widely among different
participants. Most respondents (52.5%) were from the central-west area of Maryland (Frederick, Washington and Carroll counties), but all six major regions of the state were represented in the sample population.

4.4.3 Scale of poultry production

Respondents answered questions related to the production scale of their poultry operations. The results are displayed graphically below in Figures 4-1 and 4-2. Figure 4-1 shows the total yearly production volume of all the direct-market poultry producers who responded to the survey questionnaire (N=40). Figure 4-2 displays the distribution of yearly processing volume of broiler poultry among respondents using on-farm processing facilities (N=25) and among those using third-party processors (N=15). For producers using third-party processors (businesses that serve an unknown number of different poultry and livestock producers) this volume represents the total number of broiler poultry the survey respondent brought to third-party facilities for slaughter and processing in the last 12 months. For producers using on-farm processing facilities, this number represents the estimated total number of birds processed at their on-farm facility over same period of time. For the limited number of on-farm processors who shared use of their facility with other poultry producers (N=4), this value is the combined volume of broiler poultry processed by all the poultry farms using that facility. The outlier data point in this graph represents one individual producer who himself raised over 7,000 broiler poultry each year, but also owned an on-farm facility that was used by several other direct-market poultry producers who collectively processed an additional estimated 5,000 birds per year in this facility.

Scale was reported by respondents completing the survey in terms of yearly production volume (number of broiler poultry raised on-farm within the last 12 months) and in terms of
average flock size. Respondents also answered questions related to the methods they use to slaughter at process their poultry and the USDA-FSIS or MDA inspection and certification status of their on-farm poultry processing facility or their third-party processor. Survey data on the production scale of different groups of direct marketers, categorized by those operations using on-farm vs. third-party processors and sub-categorized based on the food safety inspection and certification status of the processing facility used, are displayed in Table 4-2.

4.4.4 Livestock production models, practices and inputs

Survey respondents answered questions about characteristics of their farm and poultry production environment. Respondents described the variety of livestock and companion animals they typically raised on their farms apart from broiler poultry, and detailed some of the models and methods used in their poultry production operation. Table 4-3 shows the distribution of different livestock and non-livestock animals maintained on the same farm as the respondent’s broiler production operation.

Survey respondents also reported the poultry housing model (mobile/pastured or permanent) employed for raising their broiler poultry livestock. Where mobile housing was in use, we asked survey respondents to provide details on how frequently their mobile poultry housing was moved onto fresh pasture. A large majority of farmers (85.0%) employed mobile poultry production systems. Among the 34 survey respondents who used mobile/pasture-based models, 70.5% (24/34) reported rotating their poultry housing onto fresh pasture daily or even more frequently; 17.6% (6/34) reported moving their poultry housing 2-3 times each week; 5.9% (2/34) moved their poultry on a weekly basis; and 2.9%
(1/34) each moved their poultry housing onto fresh pasture once every two weeks and once a month, respectively.

All 40 survey respondents reported whether they used pharmaceutical antibiotics or antimicrobial inputs in their poultry production operation. Where these inputs were reported, respondents detailed the route of administration (injection, feed or drinking water), the reason(s) for usage (therapeutic disease treatment, prophylaxis/disease prevention, and/or growth promotion), and which drugs were used. A minority (17.5%) of respondents reported using any pharmaceutical antibiotic or antimicrobial inputs in their poultry production operation. Among the 7/40 participants who did use these inputs, three reported using antibiotics only to therapeutically treat sick livestock, and all three reported exclusively using tetracycline administered through drinking water. The remaining four participants who reported using these pharmaceutical inputs all reported preventative use that was limited to recently-arrived chicks, who would receive medicated feed supplemented with coccidiostat drugs, and would be put onto non-medicated feed for the “grow-out” period of the production cycle. The starting point of the “grow-out” period for broiler poultry as defined by participants was usually between 2-3 weeks old and the length of this time extended to when the birds reach slaughter/market weight, which could be between 7-12 weeks, depending on several different factors. Coccidiostats were the only antimicrobial drug inputs for which respondents reported prophylactic use; this is standard practice, coccidia are parasites, and all parasitic control efforts employ prophylactic treatment.

4.4.5 On-farm poultry processing

Survey respondents who process their poultry products at an on-farm processing facility that they own and operate (N=25) were asked to detail the timing and methods of their
disinfection and sanitation practices for mitigating microbial contamination of the processing facility and reducing risk of cross-contamination of poultry carcasses and consumer products. These 25 respondents described whether they performed any sanitation or disinfection of processing facilities before, during and after a poultry slaughter and processing event, and were asked to detail what chemical or physical microbial decontamination methods (if any) they employed at each interval. The responses are presented in Table 4-4.

This same group of respondents who own and operate OFPP facilities were asked whether they used any sanitation methods to clean poultry carcasses with visible contamination (such as a speck of fecal matter or bile). About half (44.0%) of the 25 on-farm poultry processors included in the study said they would not sell any products to consumers if they noticed visible contamination on the carcass after processing. Instead of retailing carcasses with visible contamination, these respondents reported either washing and then consuming these birds themselves, feeding them to dogs or other non-livestock pets, or composting the carcasses on-farm for use as fertilizer. A slightly larger proportion of these 25 respondents (48.0%) reported washing any visibly contaminated carcasses with hot or cold rinse water to sanitize the carcass before chilling and packaging for sale or storage. A minority of the 25 respondents (8.0%) reported using a mild bleach solution to sanitize any visibly contaminated poultry carcasses before chilling and packaging.

On-farm poultry processors provided information about the number of full-time and part-time employees as well as unpaid volunteers that typically participated in on-farm poultry processing. These results are presented in Table 4-5.
4.5 Discussion

4.5.1 Significance and applications for public health research

The US direct-market agriculture supply chain represents a rapidly expanding commercial industry and a growing consumer market for poultry meat and other agricultural products with well-documented potential for food safety risks. The overwhelming majority of research that has been conducted, particularly public health research exploring and investigating food safety risk issues, has focused exclusively on analysis of the industrial supply chain for poultry and other agricultural products. To the best of our knowledge, this study is the first qualitative research to document and evaluate the concepts, models and practices of small-scale commercial poultry producers that inform their microbial food safety risk management paradigms and strategies. Additionally, to the best of our knowledge, our analysis of the survey data is the first quantitative research describing and analyzing the distribution of workplace characteristics and practices that are potentially directly and/or indirectly related to food safety outcomes in a statewide population of small-scale, direct-market poultry producers. This study employs an integrative model that is novel within public health research on food safety risk assessment, and in environmental health exposure research science generally. This research model provides unique strengths that helped in achieving the goals of this research.

4.5.2 Qualitative findings

The analysis of the in-depth interview data provides insights into the concepts, practices and models that collectively inform best practices and food safety risk management strategies for small-scale, direct-market poultry producers in Maryland. While standardization is a hallmark across all stations of the industrial poultry supply chain, the direct-market scale of
commercial poultry production and processing is much more frequently characterized by variety at every level. In these interviews, participants qualitatively describe their version of best practices for minimizing food safety risks for microbial contamination of their poultry products. Analysis of this collection of disparate opinions and ideas takes important initial steps toward defining the spectrum of perspectives that inform food safety risk management strategies within the Maryland direct-market poultry supply chain. These data provide a unique and important source of information on food safety issues and risk management in this emerging commercial market, as well as a framework for future research evaluating food safety health issues in direct-market production systems for poultry or other agricultural products. One practical application of this qualitative data and analysis to further, more in-depth investigations of the direct-market poultry supply chain is demonstrated in the development of the survey questionnaire tool used to generate the quantitative findings in the second stage of this study.

4.5.3 Quantitative findings
The survey data document the frequency and distribution of particular structural elements and workplace practices of direct-market poultry operations that had been previously identified by the in-depth interview group as important or relevant to microbial food safety. Demographic factors of the statewide supply chain, such as: an estimated number of direct-market poultry retailers (and amenable third-party poultry processors) currently operating in the state, the scale of direct-market poultry production and processing among this statewide population, geographic distribution of direct-market poultry production facilities, and other demographic factors are explored in this study for the first time in Maryland, and to the best of our knowledge, anywhere in the US. These data demonstrate that Maryland direct-market commercial poultry farmers are a relatively small and highly dynamic population, that they
are rarely (if ever) exclusively engaged in poultry production and sales, generally opting instead to integrate broiler poultry into an on-farm system including other livestock and agricultural crop production. These data further demonstrate that small-scale poultry production operations are generally not co-located with industrial scale poultry production (on the Maryland Eastern Shore/Delmarva Peninsula). Poultry farmers from the same geographic areas tended to know one another (as evidenced by the findings from the snowball sampling used during recruitment) but had little familiarity with small-scale poultry farmers from other regions of the state.

The quantitative data pertaining to the frequency and distribution of broiler poultry production, slaughter and processing practices also provides the first public health research insights into the different models and inputs that characterize small-scale poultry production and may have an impact on microbial food safety outcomes within this supply chain. These data demonstrate that a majority of Maryland direct-market poultry producers use on-farm poultry processing systems, and that among these on-farm processors, a wide variety of different models and practices are used. This study describes this variety in both on-farm poultry processing and small-scale commercial poultry production. These data also demonstrate that most direct-market poultry producers raise fewer than 2,000 birds per year, and that even the largest direct-market producers are not approaching the 20,000 bird/year cutoff established for PPIA exemption from USDA-FSIS. Other important findings from these data include the information on the usage of synthetic antimicrobials in small-scale commercial poultry production. The low reported rates of antimicrobial inputs combined with the data indicating that antimicrobial inputs are only used therapeutically (or as a prophylaxis for coccidiosis) indicate that this supply chain is characterized by a different paradigm for antimicrobial usage in poultry production than the industrial poultry supply
chain. These data can be applied in a variety of ways to begin to define food safety and other health and research-related issues and research questions for closing the research gap in which the direct-market supply chain for poultry and other agricultural products generally exists. Information on the variety of standard practices, food safety controls, and disinfection and sanitary procedures used during on-farm poultry processing can be applied to form directed research questions for observational and experimental studies to establish commercial best practices and science-based strategies for microbial food safety risk reduction in small-scale poultry processing. For example, sequential sampling of live animals prior to processing, and repeated sampling of carcasses, facilities, workers and equipment over the duration of a processing event, carried out in a variety of different on-farm poultry processing facilities could provide data that could be used to better determine which specific practices, models and other factors are associated with risks of microbial contamination of consumer poultry products in this supply chain.

4.5.4 Integrative methods approach

The sequential exploratory model used in this study offered distinct benefits to the study goal of evaluating a complex phenomenon in a novel environment with little to no relevant body of research available to that could be used to check assumptions or inform directed research questions. In lieu being able to refer to a body of scientific research to meet these study requirements, we employed the two-stage model of the sequential exploratory approach, and used in-depth, open-ended interviews with key informants to inform the research questions evaluated in the survey questionnaire. By leveraging the knowledge base of our key informants’ professional perspectives and opinions on food safety risk issues and risk management strategies, we were able to directly inform the content of the survey tool used to generate data for a targeted inquiry within a representative sample of the statewide
supply chain. Without the initial input gathered from key informants, the research questions covered in the survey could not have been tailored to investigate this landscape of statewide producers, and we would have essentially been without an informed starting point for conducting this investigation. The quantitative results integrate with the qualitative data to show the distribution, frequency, and (statewide) generalizability of the characteristics and practices identified during interviews as important to microbial food safety outcomes.

Mixed and integrative research strategies are an emerging trend in environmental health exposure science research. This study demonstrates the application of an integrative methods strategy to exploratory health exposure research in a novel environment, and provides a model for how this strategy can be applied as a tool in performing exposure-based risk assessments in novel research environments.

4.5.5 Drivers for antimicrobial resistance

Of particular note among the factors highlighted during interviews and reported in the survey responses was the distribution of practices related to the use of antibiotic or antimicrobial inputs among the direct-market poultry producers. Any reported use of these inputs was rare among respondents, and what usage was reported occurred under different conditions that those understood to drive selective pressure for survival and propagation of MDR foodborne pathogens in the industrial poultry supply chain. The standard practices of industrial-scale broiler poultry production include routine administration of subtherapeutic doses of antimicrobials and antibiotics as a growth promoter or for disease prophylaxis among large poultry flocks [15]. In contrast, a low number of respondents from the direct-market supply chain reported use of any subtherapeutic antimicrobial inputs for disease prophylaxis in poultry flocks. Moreover, the antimicrobial inputs used by these respondents
included only a single coccidiostat antimicrobial, namely, amprolium. Amprolium is a thiamine-uptake blocker that prevents carbohydrate synthesis in protozoa and is used to prevent the parasitic (protozoan/eukaryotic) disease coccidiosis in poultry. In contrast with many other pharmaceutical inputs applied to poultry livestock disease prevention, this antimicrobial mechanism is generally understood to be only weakly (if at all) associated with trends of acquired antimicrobial resistance (AMR) in bacterial/prokaryotic populations. The only other reported antimicrobial inputs used in the statewide supply chain were among a small minority of poultry farmers who reported using one antibiotic therapy (tetracycline administered in drinking water) to therapeutically treat sick or infected birds. All respondents reporting use of therapeutic tetracycline in poultry production also acknowledged that use of this input was not standard practice for their operation, and that they would generally only treat sick birds with antibiotics as a last resort after applying interventions such as quarantining or culling individual sick birds to prevent intra-flock contagion, changing out poultry bedding and/or moving birds to new pasture, and/or using non-pharmaceutical therapies such as supplementing poultry drinking water with apple cider vinegar. These respondents also reported that they would not sell birds treated with tetracycline to consumers (instead consuming the meat themselves). These respondents noted that poultry livestock illness and infection was infrequent and atypical in their operation, and thus only rarely necessitated the use of therapeutic tetracycline inputs.

The frequency and distribution of responses related to antimicrobial inputs raises some interesting research questions about the epidemiology of AMR genes and phenotypes in microbial populations (particularly foodborne pathogens) associated with direct-market poultry supply chain. The practices and inputs reported by small farmers related to antimicrobial usage in poultry production depart substantially from the practices and inputs
demonstrated to drive selective pressure for multidrug resistant bacterial pathogens in
industrial-scale poultry production. It follows that the populations of foodborne pathogens
associated with the direct-market poultry supply chain may be characterized by substantially
different trends and distribution of antimicrobial resistance genes and phenotypes than those
microbial populations associated with the US industrial poultry supply chain. Analyzing the
epidemiology of AMR genes and drug-resistance phenotypes among populations of
pathogenic bacteria associated with alternative models of livestock production and
underexplored niche environments of the US food system is a timely and important topic for
public health research.

4.5.6 Strengths, limitations and areas for further research

This exploratory research benefitted from different strengths that helped in achieving our
study goals. One particular strength of this study is that we were able to obtain responses to
the survey questionnaire from a representative sample of the study population (the total
population of direct-market poultry producers currently operating in Maryland). The 40
respondents represent a majority of the total statewide population meeting these inclusion
criteria. While the exact proportion of sample population : study population is difficult to
measure, we are confident that the methods we used to identify and estimate the size of the
study population provided the most comprehensive and accurate measurement of study
population size possible, given the circumstances. The particular condition that makes this
measurement difficult to accurately ascertain is the high business turnover rate of small
commercial poultry operations in Maryland. This function of the direct-market poultry
supply chain was mentioned by some participants during in-depth interviews, and is readily
evidenced by the large number of defunct poultry operations that were still registered in
online databases (indicating that they had been in business in recent years), and the high
proportion (~50%) of respondents who had 5 years or less of commercial experience in direct-market poultry farming. Despite this limitation, we feel confident that the estimate of N≈66 (50 positively identified farms + 16 non-responses from commercial databases counted as passive refusals) is an acceptably accurate measurement of the current population of direct-market poultry producers operating in Maryland for the purposes of assessing the generalizability of our findings. Given the estimated response rate of 61%, we believe the findings of this study are likely to be highly generalizable at the statewide level. However, it should be noted that this data only represents a momentary snapshot of a highly dynamic system; the factors measured in this study (along with other emerging issues potentially affecting microbial food safety) are likely to change over time. Tracking the evolution of these trends is important to establishing a working understanding of direct-market production systems for poultry and other agricultural products. It is also reasonable to assume that some factors intrinsic to direct-market poultry production and relevant to microbial food safety may be considerably different in other regions of the US. The differences in food safety policy between different states may also increase the likelihood of interstate variability for factors related to these issues. However, it is possible that there may also be a regional effect in the generalizability of this research, wherein the issues explored in this study among direct-market poultry producers may be more similar in regions and small-scale poultry supply chains proximate to Maryland than in those more geographically distant. Further investigation into these topics should include states inside and outside of the Mid-Atlantic region to establish the validity of such a regional effect.

As mentioned earlier, the sequential exploratory study design provided particular benefits to the study goals of exploring and describing a complex phenomenon in a novel environment. The qualitative findings are externally validated by the responses to the survey tool among
the broader sample population, indicating that the issues highlighted by the 16 interviewees were also relevant and generalizable to the food safety risk management strategies of the 40 survey respondents, who in turn represent a majority of the estimated study population. However, as with most exploratory research in environmental health science, the focus of this study is descriptive, rather than to define or measure any particular relationships. More in-depth research will be required to analyze any relationships between the different factors identified and measured in this study (along with other potential factors yet to be identified) and their relationship, if any, to relevant microbial food safety outcomes. An important future research topic building on the findings of this study is an evaluation of the prevalence of poultry livestock-associated AMR and antimicrobial-susceptible foodborne pathogens in the direct-market poultry retail meat products sold in Maryland, the Mid-Atlantic region, and other areas of the US.
4.6 Acknowledgments

I would like to acknowledge Dr. Shannon Frattaroli for her input in study design and data reporting and analysis. Dr. Meghan Davis and Dr. David Love both provided comments and proofreading for this manuscript.

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4.7 References


Figure 4-1: Production Volume (birds/year) of Direct-Market Poultry Producers (N=40)
Figure 4-2: Yearly Processing Volume of Direct-Market Poultry Producers
Table 4-1: Demographics of Survey Questionnaire Respondents (N=40)

<table>
<thead>
<tr>
<th></th>
<th>Female (60%)</th>
<th>Male (40%)</th>
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<tbody>
<tr>
<td><strong>Racial Background</strong></td>
<td>White/Caucasian (100%)</td>
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</tr>
<tr>
<td><strong>Years of Experience</strong></td>
<td>Median: 5.5; IQR: 2.5-10.0</td>
<td></td>
</tr>
<tr>
<td><strong>Statewide Location:</strong></td>
<td>15/22 MD Counties (68.2%)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Region (%)</th>
<th>County (%)</th>
</tr>
</thead>
</table>
| Central-West (52.5%) | Frederick (27.5%)  
|             | Washington (12.5%)  
|             | Carroll (5.0%)  
|             | Montgomery (5.0%)  
|             | Howard (2.5%)  |
| Northern (25.0%) | Harford (17.5%)  
|                   | Baltimore Co. (7.5%)  |
| Southern (5.0%) | Prince George’s Co. (5.0%)  |
| Eastern Shore (10.0%) | Cecil (2.5%)  
|                       | Caroline (2.5%)  
|                       | Dorchester (2.5%)  
|                       | Wicomico (2.5%)  |
| Western Shore (2.5%)  | Calvert (2.5%)  |
| Far West (5.0%)       | Allegany (2.5%)  
<p>|                       | Garrett (2.5%)  |</p>
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<thead>
<tr>
<th>Processor Location</th>
<th>Total (N=40)</th>
<th>On-Farm (N=25)</th>
<th>Third Party (N=15)</th>
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<tr>
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<td>Total (N=40)</td>
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<td>MDA (N=18)</td>
</tr>
<tr>
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<td>1,050 (450-1,700)</td>
<td>2,700 (2,700)</td>
<td>1,200 (800-2,500)</td>
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<tr>
<td>MDA</td>
<td>30-7,300</td>
<td>2,700-2,700</td>
<td>30-7,300</td>
</tr>
<tr>
<td>Neither</td>
<td>100 (50-150)</td>
<td>200 (200-200)</td>
<td>70 (50-100)</td>
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<td>Range: Birds/yr.</td>
<td>2,000-7,300</td>
<td>2,700-2,700</td>
<td>30-7,300</td>
</tr>
<tr>
<td>Median (IQR): Flock Size</td>
<td>100 (50-150)</td>
<td>200 (200-200)</td>
<td>70 (50-100)</td>
</tr>
<tr>
<td>Range: Flock Size</td>
<td>10-500</td>
<td>200-200</td>
<td>10-500</td>
</tr>
</tbody>
</table>
Table 4-3: Non-Broiler Poultry Livestock and Companion Animals Maintained on Direct-Market Poultry Farms

<table>
<thead>
<tr>
<th>Livestock Type (%)</th>
<th># Livestock Species (%)</th>
<th>Pets Type (%)</th>
<th># Pets Species (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swine (65.0%)</td>
<td>1+ (100.0%)</td>
<td>Dog (80.0%)</td>
<td>1+ (97.5%)</td>
</tr>
<tr>
<td>Beef Cattle (52.5%)</td>
<td>2+ (97.5%)</td>
<td>Cat (70.0%)</td>
<td>2+ (67.5%)</td>
</tr>
<tr>
<td>Egg-Laying Hens (50.0%)</td>
<td>3+ (90.0%)</td>
<td>Horse (20.0%)</td>
<td>3+ (15%)</td>
</tr>
<tr>
<td>Turkeys (35.0%)</td>
<td>4+ (60.0%)</td>
<td>Dove (5.0%)</td>
<td>4+ (5.0%)</td>
</tr>
<tr>
<td>Sheep (32.5%)</td>
<td>5+ (32.5%)</td>
<td>Donkey (5.0%)</td>
<td>5+ (2.5%)</td>
</tr>
<tr>
<td>Goats (25.0%)</td>
<td>6+ (17.5%)</td>
<td>Fish (5.0%)</td>
<td>6+ (0.0%)</td>
</tr>
<tr>
<td>Other Poultry (12.5%)</td>
<td>7+ (7.5%)</td>
<td>Llama (2.5%)</td>
<td></td>
</tr>
<tr>
<td>Dairy Cattle (10.0%)</td>
<td></td>
<td>Kangaroo (2.5%)</td>
<td></td>
</tr>
<tr>
<td>Rabbits (7.5%)</td>
<td></td>
<td>Monkey (2.5%)</td>
<td></td>
</tr>
<tr>
<td>Other Livestock (2.5%)</td>
<td></td>
<td>Peacock (2.5%)</td>
<td></td>
</tr>
</tbody>
</table>
Table 4-4: Disinfection Practices of Participating OFPP Facilities (N=25)

<table>
<thead>
<tr>
<th>Pre-Processing (%)</th>
<th>During Processing (%)</th>
<th>Post-Processing (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Any Disinfection (100.0%)</td>
<td>Any Disinfection (44.0%)</td>
<td>Any Disinfection (100%)</td>
</tr>
<tr>
<td>Bleach Solution (84.0%)</td>
<td>Bleach Solution (24.0%)</td>
<td>Bleach Solution (76.0%)</td>
</tr>
<tr>
<td>Soap Water (72.0%)</td>
<td>Soap Water (16.0%)</td>
<td>Soap Water (48.0%)</td>
</tr>
<tr>
<td>Hot water (12.0%)</td>
<td>Hot water (4.0%)</td>
<td>Hot water (16.0%)</td>
</tr>
<tr>
<td>Vinegar/Peroxide (12.0%)</td>
<td>Vinegar/Peroxide (4.0%)</td>
<td>Vinegar/Peroxide (8.0%)</td>
</tr>
<tr>
<td>UV (Sunlight) (4.0%)</td>
<td>Salt Water (4.0%)</td>
<td>UV (Sunlight) (12.0%)</td>
</tr>
<tr>
<td>No soap, no bleach (4.0%)</td>
<td>No soap, no bleach (76.0%)</td>
<td>No soap, no bleach (16.0%)</td>
</tr>
<tr>
<td>2+ cleaning agents (76.0%)</td>
<td>2+ cleaning agents (16.0%)</td>
<td>2+ cleaning agents (64.0%)</td>
</tr>
</tbody>
</table>
Table 4-5: Number and Employee Status of Workers Participating in OFPP

<table>
<thead>
<tr>
<th>OFPP Type</th>
<th># Farms (%)</th>
<th>Employee Status</th>
<th>Median (IQR) # workers</th>
<th>Range # workers</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Farms</td>
<td>25/25 (100.0%)</td>
<td>All</td>
<td>3 (3-5)</td>
<td>1-14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FT</td>
<td>3 (3-5)</td>
<td>1-14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PT</td>
<td>0 (0-1)</td>
<td>0-8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Volunteer</td>
<td>1 (0-1)</td>
<td>0-7</td>
</tr>
<tr>
<td>FT Employees Only</td>
<td>9/25 (36.0%)</td>
<td>All/FT</td>
<td>3 (2-3)</td>
<td>1-9</td>
</tr>
<tr>
<td>FT/PT Employees</td>
<td>3/25 (12.0%)</td>
<td>All</td>
<td>2 (2-10)</td>
<td>2-10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FT</td>
<td>1 (1-2)</td>
<td>1-2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PT</td>
<td>1 (1-8)</td>
<td>1-8</td>
</tr>
<tr>
<td>FT Employees + Volunteers</td>
<td>6/25 (24.0%)</td>
<td>All</td>
<td>4 (3-5)</td>
<td>2-8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FT</td>
<td>1.5 (1-2)</td>
<td>1-2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Volunteers</td>
<td>2 (1-4)</td>
<td>1-7</td>
</tr>
<tr>
<td>FT/PT Employees + Volunteers</td>
<td>7/25 (28.0%)</td>
<td>All</td>
<td>4 (5-12)</td>
<td>3-14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FT</td>
<td>2 (2-3)</td>
<td>1-3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PT</td>
<td>1 (1-6)</td>
<td>1-8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Volunteers</td>
<td>1 (1-2)</td>
<td>1-5</td>
</tr>
</tbody>
</table>
Chapter Five

**Manuscript Four:** Prevalence and Antimicrobial Susceptibility Phenotypes of *Escherichia coli*, *Staphylococcus aureus*, and *Salmonella spp.* in the Maryland Direct-to-Consumer Supply Chain for Broiler Poultry Meat Products
Abstract: The purpose of this study was to use a cross-sectional, market-basket analysis of the Maryland direct-to-consumer commercial broiler poultry supply chain to assess the prevalence and antimicrobial-susceptibility phenotypes of pathogenic bacterial species isolated from poultry meat products. We purchased 40 frozen poultry meat products from 40 unique direct-to-consumer commercial poultry farming operations in Maryland. Microbial analysis of poultry meat products included culture-based sampling for *E. coli*, *S. aureus* and *Salmonella* spp. and subsequent testing of all culture-positive isolates for species confirmation and resistance phenotypes against a broad spectrum of antimicrobial classes using the BD Phoenix automated system. *E. coli* and *S. aureus* were recovered from 9/40 (22.5%) and 12/40 (30.0%) of poultry meat samples, respectively. No positive *Salmonella* isolates were recovered from any poultry products sampled in this study. Among positive isolates of *E. coli* and *S. aureus*, resistance to more than one class of antimicrobials was low; no multidrug resistance (resistance to 3+ classes of antimicrobials) was observed in any isolates. The findings of this study indicate that poultry products sold through the direct-market agriculture supply chain in Maryland may be characterized by prevalence rates of multidrug-resistant microbial foodborne pathogens that are lower than rates observed for products sampled through the National Antimicrobial Resistance Monitoring System. Non-detection of *Salmonella* spp. does not necessarily indicate that this pathogen is absent from this supply chain, but does suggest that the factors affecting survival and recovery of viable *Salmonella* spp. in this environment are complex and yet to be fully defined.
5.1 Introduction

5.1.1 Incidence and trends in foodborne illness in the US
The CDC estimates that 1 in 6 people in the US (~48 million people) are sickened each year by foodborne illness, with an additional 128,000 hospitalizations and an estimated 3,000 annual deaths [1]. Foodborne *Salmonellosis* caused an estimated 1,027,561 cases of foodborne illness in 2013 in the US (15.2 cases per 100,000), and resulted in 19,000 hospitalizations and 380 deaths. These estimates identify non-typhoidal *Salmonella* as the second most common foodborne pathogen implicated in foodborne illness in the US (following only norovirus), as the agent responsible for the highest numbers of hospitalizations and deaths in the US each year due to foodborne illness [2]. Other bacterial pathogens commonly associated with foodborne illness include *C. perfringens* (~965,958 cases of domestic foodborne illness in 2013; 15.1 per 100,000), *Campylobacter spp.* (~845,024 cases; 13.8 per 100,000), and *S. aureus* intoxication (~241,148 cases; 3.6 per 100,000) [2]. Incidence of O157 and non-O157 Shiga-toxin producing *E. coli* (STEC) are also tracked by the CDC active surveillance program, causing illness at rates of 1.15 and 1.17 per 100,000, respectively. An estimated ~80% of cases of foodborne infection, and ~56% of hospitalizations and deaths in the US due to foodborne illness are attributed to an unknown agent [3].

5.1.2 Poultry meat and foodborne illness
A review of food safety outbreak data in the US from 1998-2008 indicates that poultry products contaminated with pathogenic bacteria were responsible for an estimated 653,622 cases of foodborne illness annually, comprising 17.9% of foodborne illness cases caused by exposure to bacteria [4]. Poultry meat is also the food product category most frequently implicated in deaths resulting from foodborne illness, causing ~19% of all cases of foodborne illness resulting in death [2].
5.1.3 Selective pressure for antimicrobial resistance among foodborne pathogens

Modern industrial food animal production is characterized by two factors that are demonstrated to facilitate selection for antibiotic resistance among zoonotic pathogens: (1) high density animal production and (2) routine use of antimicrobials for production, prevention and therapeutic purposes [5-9]. Antimicrobial resistance among foodborne bacterial pathogens is a serious complicating factor in foodborne illness; antimicrobial-resistant infections resulting from human exposure to foodborne bacteria caused an estimated 430,000 illnesses in the US in 2012 [10, 11]. Based on the previous research conducted on the commercial population of Maryland direct-market poultry retailers, it was established that the paradigm for on-farm practices relevant to density of livestock production and usage of on-farm antimicrobial inputs is typically substantially different in this supply chain compared to the paradigm for conventional industrial-scale poultry production. The model(s) currently in use for direct-market poultry production have not been adequately investigated in the research literature for their potential to facilitate selective pressure for antimicrobial resistance in foodborne pathogens.

5.1.4 Salmonella

*Salmonella spp.* is a genus of Gram-negative, rod-shaped bacteria in the *Enterobacteriaceae* family known to cause human illness. Salmonellosis is a common human disease typically characterized by onset of symptoms within 12-72 hours post-infection, with symptoms generally including abdominal cramps, fever, and diarrhea. Symptoms generally resolve within 4-7 days, but may occasionally involve serious dehydration which requires hospitalization. There are also rare cases of reactive arthritis to Salmonellosis, where after the acute symptoms have resolved, people develop long-term joint pain which may last for months or years, and increases risk of chronic arthritis [2]. Though *Salmonella* exposure is
attributed to contamination of a wide variety of foods, poultry meat and egg products are the most frequent routes of human foodborne exposure in the US [4]. Antimicrobial resistance is a major issue among non-typhoidal Salmonella species associated with food safety risks. Multidrug-resistant non-typhoidal Salmonella infections (from food or other sources) caused an estimated 100,000 cases of illness complicated by drug-resistance in the US in 2013 [11].

5.1.5 E. coli

Escherichia coli is a gram-negative, facultatively anaerobic, rod-shaped bacterium, belonging to the same family as Salmonella. E. coli are commonly found in the lower intestinal tracts of most warm-blooded animals. Most E. coli are harmless, but a handful of serovars are associated with illness in humans, including food poisoning. Most of the pathogenic serovars associated with food poisoning are Shiga-toxin producing strains of E. coli (STEC). STEC infections are associated with hemolytic-uremic syndrome (HUS), which is characterized by hemolytic anemia potentially complicated by acute kidney failure [12]. While STEC infection rates are relatively low compared to incidence rates of Salmonellosis in cases of food poisoning in the US, a high proportion of these illnesses result in hospitalization due to complications from HUS, which also carries a 5-10% mortality rate [12]. STEC E. coli are associated with high rates of multidrug resistance; one recent study isolating STEC from meat and dairy products reported rates of multidrug resistance in excess of 50% [13]. A recent literature review theorizes a dramatic change to the traditional paradigm for understanding the pathogenic potential of E. coli as a foodborne disease agent. The review’s findings indicate that strains of E. coli traditionally associated with food poisoning symptoms may also contribute to the burden of human urinary tract infections (UTIs) and that many UTIs may have a direct foodborne origin for exposure. The study further notes that the foodborne illness-associated UTIs are associated with high rates of multidrug resistance [14].
5.1.6 Salmonella and E. coli Contamination of US Poultry Products: NARMS

Food safety surveillance for prevalence and AMR characteristics of E. coli and non-typhoidal Salmonella (along with Campylobacter and Enterococcus) in the US retail meat supply chain is carried out by the National Antimicrobial Resistance Monitoring System (NARMS), a collaborative effort of the CDC, the US Food and Drug Administration (FDA) and the US Department of Agriculture (USDA). NARMS performs an annual cross-sectional analysis of market-basket meat samples from the US supply chain and monitors for changes over time in the prevalence and antimicrobial-resistance phenotypes of these four bacteria on raw chicken, ground beef, ground turkey and pork chops [15]. NARMS recently released the preliminary analysis of their most up-to-date (2013) data for Salmonella prevalence in raw chicken products. Salmonella isolates were recovered from 208/1669 samples taken nationwide (12.2%), and 26.0% of positive isolates were MDR; 28/120 poultry samples from Maryland were Salmonella positive, and 23.3% of these isolates were MDR [16]. These preliminary results are somewhat lower than NARMS prevalence rates for Salmonella in 2012, which reported 229/1300 Salmonella positive samples (17.6%) with 33.2% MDR isolates nationwide, and 57/120 (47.5%) Salmonella-positive samples from poultry purchased in Maryland supermarkets [15].

The most recent available (2012) NARMS data for nationwide and statewide E. coli prevalence on raw poultry products reported 386/480 (80.4%) samples positive nationwide for E. coli contamination with 29.8% MDR isolates, and 92/120 (76.7%) overall E. coli prevalence among Maryland samples [15]. The previous year reported 341/480 (71.0%) E. coli prevalence in nationwide raw poultry samples with 37.5% MDR isolates and 50/120 (41.7%) E. coli prevalence in Maryland samples [17].
5.1.7 *S. aureus* and poultry

*Staphylococcus aureus* is a Gram-positive, facultatively anaerobic, coagulase-positive coccal bacterium known to frequently colonize and infect humans, several common livestock and companion animal species, and a variety of wildlife. *S. aureus* is environmentally hardy and adaptive; it has evolved to survive and reproduce in many ecological and human environments, including the anthropomorphic ecologies of US food animal production systems [7, 46]. *S. aureus* is an opportunistic pathogen in humans, and a frequent cause of skin infections, respiratory disease and food poisoning. Methicillin-resistant *S. aureus* (MRSA) and multidrug resistant *S. aureus* (MDR-SA) are associated with serious human diseases with exposure pathways originating in and circulating through healthcare settings, communities and industrial food animal production [7, 47, 48, 49].

NARMS does not include *S. aureus* as part of their retail meat surveillance strategy, and only a relatively small number of independent studies have evaluated prevalence of *S. aureus*, MDR-SA and MRSA in US poultry meat. While MRSA has not demonstrated to colonize poultry meat products at high rates in this research, *S. aureus* has been consistently reported to contaminate consumer poultry meat in the US, sometimes with observed prevalence rates as high as 65% [18]. *S. aureus* is more typically reported to contaminate between 11-40% of consumer raw poultry meat products sampled from the industrial supply chain [19, 20, 21]. Prevalence of MDR-SA has been infrequently reported in the few existing market-basket studies evaluating *S. aureus* prevalence in the US poultry meat supply chain; with one single study reporting 26% prevalence of MDR-SA among *S. aureus* isolates recovered from contaminated poultry meat products [21]. Other studies have reported rates of resistance to one and two classes of antimicrobials among *S. aureus* isolates recovered from poultry meat. Hanning *et al.* reported resistance rates of 36% and 20% to 1+ and 2+ classes of
antimicrobials, respectively, among *S. aureus* isolates sampled from retail meat [20], while Hanson *et al.* reported AMR rates of 62.5% and 12.5% of recovered *S. aureus* isolates to 1+ and 2+ antimicrobial classes, respectively [19].

5.1.8 Microbial food safety in direct-market poultry systems

The prevalence of microbial foodborne pathogens, including *Salmonella*, *E. coli* and *S. aureus*, in consumer poultry meat products issuing from the direct-market poultry supply chain, remains almost completely unexplored in public health research. To the best of our knowledge, only a handful studies have attempted to evaluate microbial food safety risks in direct-market poultry supply chains; only one study addressed these issues through a market-basket and consumer exposure research lens [22]. This single study, which sampled whole fresh (*n*=60) and frozen (*n*=40) chicken carcasses purchased from 21 vendors at different farmers’ markets in Pennsylvania, evaluated the prevalence of non-typhoidal *Salmonella* and *Campylobacter* on whole carcasses, and compared these results to comparable microbial data obtained from analyzing USDA-Organic and conventional poultry meat at Pennsylvania supermarkets. The study demonstrated high prevalence (85% and 93% for frozen and fresh samples, respectively) of *Campylobacter* contamination for poultry purchased from farmer’s market vendors, significantly higher than conventional (52%) or Organic (28%) chicken samples. Prevalence of non-typhoidal *Salmonella spp.* was reported to be statistically significantly higher in farmer’s market poultry than for conventional poultry products (28% and 8%, respectively), and higher than Organic poultry meat (20%) [22]. While this research is a first step in filling in the knowledge gap for food safety issues in direct market poultry supply chains, this study contains (and significantly, does not report) obvious limitations to interpretations of the study data. No power or sample size calculations are reported for assessing statistical significance of any of the reported associations; and there is no
description of an attempt to define the overall study population (total number of direct-market poultry producers in Pennsylvania) to determine the representativeness of the pool of study participants (n=21 vendors). Relevant data that can generally be obtained from the label of the consumer product, such as whether the bird was slaughtered and processed at a USDA-FSIS inspected facility, a state-inspected facility, or an uninspected on-farm processing facility, are not reported. The study assumes that all vendors practice on-farm poultry slaughter and processing under FSIS-exemption, but does not verify or report this important information, which may not be accurate in many cases. Our survey of Maryland direct-market poultry vendors found that over 37% of these producers use a third-party processor that is not located on their farm, and that 30% processed their broiler poultry livestock at a USDA-FSIS inspected facility. Finally, the study conducted by Scheinberg et al. does not assess antimicrobial-resistance characteristics of foodborne pathogens in their market-basket sample. Given the critical significance of antimicrobial resistance in zoonotic and foodborne pathogens for food safety and public health in general, this is a major omission in any attempt to characterize microbial food safety risk issues in the direct-market poultry supply chain.

The growing importance of statewide direct-marketing systems for poultry and other agricultural products requires filling in this research gap surrounding microbial food safety in this niche of the consumer food supply chain. This study builds on the previous research we have done in this population of Maryland direct-market poultry producers. Our earlier research in this population demonstrated that the models, practices and inputs used in Maryland direct-market poultry production depart substantially from the typical models and practices of industrial-scale poultry production. We hypothesize that these inter-supply chain differences, particularly the different paradigms for usage of antimicrobial inputs in small-
scale poultry production, contribute to different microbial food safety outcomes for consumer poultry products in this supply chain than those typically observed in the industrial food system, particularly with regard to the prevalence of MDR foodborne pathogens. This study has four specific aims: (1) describe the prevalence of *Salmonella* spp., *E. coli*, and *S. aureus* in a market-basket sample of raw poultry meat purchased in the Maryland direct-market poultry supply chain; (2) characterize the antimicrobial resistance phenotypes of any cultured isolates; (3) compare these outcomes to relevant food safety data from NARMS and other independent peer-reviewed research; and (4) use matched data obtained with a survey tool from the same participating farms and poultry processors to observe for any signals or trends that may be related to observed food safety outcomes.

### 5.2 Methods

To achieve Aims 1-3 for characterizing microbial food safety trends in this statewide commercial population, we employed a market-basket sampling strategy to assess commercial poultry products for microbial food safety outcomes. We used laboratory culture methods and the BD Phoenix automated microbiology system for species confirmation and antimicrobial susceptibility testing. To achieve Aim 4, we returned to matched survey data obtained from the same sample population to see if any patterns or signals emerged when independent variables were derived from these data and fitted to a logistic regression analysis as well as a variety of nonparametric tests of association to predict binary outcomes for microbial contamination and antimicrobial resistance. Survey data and other data from our previous research on this study population are also integrated with market-basket data to contextualize and interpret these findings outside of the realm of statistical significance.
5.2.1 Enrollment and Recruitment

For an earlier stage of this research, we surveyed 40 Maryland direct-market poultry farmers to assess the distribution of food safety-related practices and models employed for poultry production and processing in this commercial population. These surveys were administered in person by the lead investigator, and a sample of frozen poultry was purchased at the conclusion of each survey with the respondent’s consent. Survey respondents were informed of the aims of the retail meat analysis, including evaluating a microbial profile of their product to compare with certain characteristics related to their operation and practices (collected during the survey), and asked for oral consent to include a sample of their poultry meat in the market-basket study. The inclusion and exclusion criteria, assessment of the study population, and enrollment and recruitment strategies and methods are all the same as those described in Chapter Four for the methods of the survey questionnaire in the earlier research performed on this population.

5.2.2 Sample collection, transport and storage

All 40 poultry retailers who completed the survey provided oral consent to anonymously submit a single poultry meat sample from their retail store for microbial analysis, and were recruited and included in the market-basket stage of this research. Poultry meat samples were collected by the lead investigator at the conclusion of the survey visit. Because results from a prior stage of research indicated that frozen products were the most common products marketed by this population, fresh poultry was excluded from the sample pool and only frozen products were obtained for microbial assessment. Samples were transported in an electric cooler powered by the 12V outlet in the car that was used to travel from the vendor locations to the laboratory. Frozen poultry samples were not allowed to thaw during transport to the laboratory freezer. Storage time between sample purchase date and date of
thawing for laboratory analysis was recorded along with information on the label (where available) on initial product processing/freezing date.

5.2.3 Lab culture and antimicrobial-susceptibility testing methods: Salmonella spp.

Laboratory culture methods for *Salmonella spp.* were adapted from NARMS protocols for culture-based methods for retail meat surveillance [15]. Packages of frozen meat were set out in open coolers in the lab 12-16 hours in advance and allowed to warm to room temperature. Thawed packages were opened aseptically using sterile surgical instruments, then two 25 gram aliquots of surface muscle tissue, skin, and fat were removed, weighed and placed into a stomacher bag containing either 200 ml of double-strength lactose broth (Becton Dickinson-Difco) or 200 ml of 0.9% saline solution. Both aliquots were agitated and vigorously shaken for 60 seconds. 15 ml of the rinsate from the aliquot in the lactose broth was pipetted into a sterile centrifuge tube, vortexed, and incubated overnight at 35°C. Fifty milliliters of rinsate was then pipetted from the aliquot in saline solution and vortexed with 50 ml of double-strength lactose broth in a sterile flask and the contents were mixed thoroughly. Fifteen milliliters of this mixture was pipetted into a sterile centrifuge tube and incubated for 24 hours at 35°C with the tubes from the enrichment broth stomacher bag. From each tube, 0.1 ml was pipetted into 9.9 ml of Rappaport-Vassiliadis Medium (BD-Difco) and incubated for 16-20 hours at 42°C. One milliliter of these enrichment broths was transferred to 10 ml tubes of pre-warmed M-broth (BD-Difco) and incubated at 35°C for 6-8 hours. The broth mixtures were allowed to cool to room temperature and 10 μl were streaked onto Xylose Lysine Deoxycholate (XLD) agar plate (Becton-Dickinson) and incubated overnight at 35°C. After 24 hours, plates were examined for colonies typical for *Salmonella* growth (pink colonies with or without black centers). Any typical colony was streaked to a trypticase soy agar plate supplemented with 5% defibrinated sheep’s blood.
(Thermo Scientific-Remel) to confirm isolate purity before using the BD Phoenix automated microbiology system for identification and antimicrobial susceptibility testing [23, 24] at the Johns Hopkins Hospital Clinical Diagnostic Microbiology Laboratory.

5.2.4 Lab culture and antimicrobial-susceptibility testing methods: E. coli

Laboratory culture methods for *E. coli* were adapted from standard food safety literature [15, 25, 26, 27, 28]. Packages were allowed to thaw and opened as described above, and a 25 gram aliquot of mixed tissue types was aseptically removed, weighed and placed in a sterile stomacher bag with 200 mL of MacConkey enrichment broth (MAC broth) (Becton-Dickinson) and shaken vigorously for 60 seconds. Fifteen milliliters of this rinsate was pipetted into a sterile centrifuge tube and incubated 16-20 hours at 35°C. Tubes were vortexed thoroughly, and 10 μl from each tube was streaked onto MacConkey agar (MAC agar) (Becton-Dickinson) plates, which were incubated 16-20 hours at 35°C. Where *E. coli*-like growth (round pink colonies with or without a dark center and a hazy area surrounding colonies) was observed, a single colony (when present) or a 1 μl loop of typical but overcrowded growth was streaked to a fresh MAC agar plate and incubated 16-20 hours at 35°C. Culture-positive isolates were confirmed and tested for antimicrobial susceptibility using the BD Phoenix system.

5.2.5 Lab culture and antimicrobial-susceptibility testing methods: S. aureus

Laboratory culture methods for recovery of *S.aureus* isolates from poultry meat samples were adapted from food safety literature on recovery of poultry livestock-associated *S. aureus* and MDR-SA [21, 29, 30]. Packages of meat were allowed to thaw and aseptically opened as described above. A 25 gram aliquot of mixed tissue was removed, weighed and placed in a stomacher bag with 200 ml of Mueller-Hinton Broth (Becton Dickinson) supplemented with 6.5% NaCl (MHB+). The bag was vigorously shaken for 60 seconds, then 15 ml was
pipetted to a sterile centrifuge tube, vortexed, and incubated 16-20 hours at 37°C. Tubes were vortexed after incubation and a 10 μl loop of enrichment broth was streaked to BAP (Thermo Scientific-Remel) and incubated 24 hours at 37°C. Plates were examined for typical *S. aureus* colonies (shiny, round, grey/white and with or without hemolysis) and either a single colony (when present) or a 1 μl loop of typical growth was streaked to a Baird-Parker (BP) agar plate (Becton-Dickinson) and incubated 24 hours at 37°C. Plates were examined for typical *S. aureus* growth (round, grey/black colonies with clearing around CPS) and culture-positive samples were confirmed and antimicrobial-susceptibility tested using the BD Phoenix system.

5.2.6 Laboratory Quality Control

Quality control was assessed for laboratory bias or error by use of positive and negative controls. Positive controls and laboratory blanks (uninoculated broth samples run through the culture protocol) each were deployed at a rate of 10% for the culture protocols of all three target species (4 blank samples and 4 ATCC-positive samples per species). ATCC 25922, ATCC 14028 (*S. enterica*), and ATCC 25923 (MSSA) were used as positive controls for *E. coli*, *Salmonella* spp. and *S. aureus*, respectively.

5.2.7 Statistical Analysis

Logistic regression and nonparametric tests were used to assess the strength and statistical significance of any relationships between the factor variables derived from the survey data and the binary outcomes of any microbial contamination, *S. aureus* or *E. coli* contamination, contamination with Gram-positive and Gram-negative bacteria, and contamination with drug-resistant CPS, CNS and/or *E. coli*. Simple and multiple logistic regression tests, along with non-parametric analyses including Fisher’s Exact Tests were used to assess inter-group differences between different categories of poultry vendors.
The Johns Hopkins Bloomberg School of Public Health Institutional Review Board approved this project.

5.3 Results

5.3.1 Enrollment and recruitment

The process for identifying and contacting eligible poultry marketers, the passive and active refusal rates, and the process by which 40/66 potentially eligible poultry operations that were identified were ultimately recruited and participated in the retail meat analysis is identical to the process described in the previous chapter for the survey questionnaire. Between October 2014 and April 2015 we collected 40 frozen poultry meat samples and completed questionnaire surveys from 40 unique direct-market poultry vendors in Maryland. The location of these 40 participants (by county) are shown on the map of Maryland displayed in Figure 5-1. Most participants were from the central-western region of Maryland, but participants were recruited from all major regions of the state.

5.3.2 Recovery of target and non-target microorganisms

Of the 40 unique meat samples that were analyzed in this study, 17/40 (42.5%) were positive for any of the three target microorganisms (Salmonella spp., E. coli and S. aureus), and 22/40 (55%) were positive for contamination with any microbial species, including non-target microorganisms. Consistent, expected results from positive and negative controls demonstrated that the protocol performed within the expected parameters.

5.3.3 Prevalence and antimicrobial-susceptibility of Gram-negative target species

E. coli was recovered from 9/40 (22.5%) of retail poultry samples. Among the nine confirmed isolates, two were resistant to one class of antimicrobials; one isolate was resistant
to tetracycline and the other to imipenem, a β-lactam/carbapenem antibiotic. No *E. coli* isolates were resistant to more than one class of antimicrobial drugs.

No positive *Salmonella* isolates were recovered from any of the retail poultry samples analyzed in this study. The dual culture protocols that used either an enrichment broth (2x lactose broth) or sterile media (0.9% saline) as an initial aliquot rinse yielded identical results.

5.3.4 Microbial prevalence and antimicrobial-susceptibility of *S. aureus*

*S. aureus* was recovered from 12/40 (30.0%) of poultry samples analyzed in this study. Of the 12 positive isolates, 6/12 (50%) were resistant to one or more antimicrobial classes, 1/12 (8.3%) was resistant to two antimicrobial classes, and none was resistant to three or more antimicrobials. All drug-resistant *S. aureus* were exclusively resistant to tetracycline, penicillin and/or ampicillin. Neither MDR-SA nor MRSA was isolated from poultry samples.

5.3.5 Prevalence of non-target microorganisms

Several samples were positive for non-target microorganisms, including one non-*S. aureus* coagulase-positive staphylococci (CPS): *S. intermedius*. The *S. intermedius* (SIG) group of staphylococci are associated with animals, including dogs and horses, and rarely may be associated with human disease [31]. The single *S. intermedius* recovered from poultry meat samples in this study was resistant to ampicillin. Other coagulase-negative staphylococci (CNS) recovered included *S. warneri* and *S. simulans* which were each isolated from 2/40 (5.0%) of poultry samples. Only a single *S. warneri* isolate displayed resistance to a single class of antimicrobials (aminopenicillins).

Gram-negative non-target microbial species included *K. oxytoca*, *S. marcescens*, and two species of *Enterobacter* (*E. cancerogenus* and *Enterobacter amnigenus* Biogroup 2). Each of these displayed antimicrobial resistance phenotypes, but all were from expression of resistance genes
intrinsic to the microbial species; no resistance phenotypes associated with mobile resistance genes or horizontal gene transfer (HGT) were noted.

5.3.6 Poultry meat samples with Gram-positive and Gram-negative contamination
Both (a) Gram-positive and (a) Gram-negative isolate(s) were recovered from 6/40 samples (15%). Table 5-2 displays the data from the Phoenix automated microbiology system for species confirmation and antimicrobial susceptibility testing for each of these “double hit” samples.

Only two *E. coli* isolates displaying drug-resistance phenotypes were recovered from the total sample pool (n=40), and both of these were recovered from two meat samples where *E. coli* co-occurred on a meat sample with an *S. aureus* isolate also displaying a resistance phenotype to one class of antibiotics. In one sample, both the *S. aureus* and *E. coli* isolates that were recovered were resistant to tetracycline.

5.3.7 Distribution of antimicrobial resistance phenotypes among CPS-positive samples
The frequency and distribution of AMR phenotypes among recovered isolates of confirmed target and nontarget microorganisms was assessed using the BD Phoenix automated microbiology system for species confirmation and antimicrobial susceptibility testing. The AMR phenotypes of all CPS recovered from poultry samples are displayed in the heat map in Table 5-3.

5.3.8 Sample freezing time
The data used to calculate the duration of time between when the poultry carcass was processed and frozen and when the samples was thawed for laboratory analysis was available for 30/40 samples. For the remaining 10 samples this information was not on the label and could not be estimated accurately by the vendor, though all vendors confirmed that
processing of purchased products occurred during the immediate past season of poultry production (i.e. within the prior 12 months of purchase). The time spent frozen for the 30 samples for which these data were available is displayed in Figure 5-2. The mean value for freezing these 30 samples was 140 days, with a range of 54-260 days and an interquartile range (IQR) of 108-150 days.

5.3.9 Microbial results analyzed in conjunction with survey questionnaire data

Responses to each of the 40 completed survey questionnaires covered food safety-relevant characteristics of the poultry production and processing operations providing poultry meat products for the 40 market-basket samples that were obtained. Data from each completed survey questionnaire was matched to a particular unique poultry sample’s microbial outcome data. Information from the survey such as whether the poultry vendor uses an on-farm or third-party processing facility, and the food safety inspection and certification status of the processing facility used (USDA-FSIS inspected, state inspected or uninspected) were used to create categories for comparing microbial outcomes among different groups of vendors. These results are displayed below in Table 5-1.

Other factors, such as the reported use of any on-farm antimicrobial inputs for therapeutic or prophylactic broiler poultry livestock disease treatment were also used to create categories for comparison of microbial outcomes between different producer groups. Seven out of 40 participants reported some on-farm antimicrobial inputs; either sporadic usage of therapeutic tetracycline to treat sick poultry livestock (3/7) or regular usage of prophylactic coccidiostat-supplemented chick feed (4/7). No positive *S. aureus* isolates were recovered from any of the poultry samples purchased from the producers reporting any antimicrobial usage. One pan-
susceptible *E. coli* isolate was recovered from a poultry sample purchased from a vendor who reported using a coccidiostat-supplemented chick feed.

Scale of yearly poultry production was also used to derive a binary variable to define two groups of producers: those retailing fewer than 1000 birds per year (n=19), and those retailing 1000 or more birds per year (n=21). Samples from the smaller-scale group tested positive for *S. aureus* contamination at a rate of 26.3%, compared to samples from the larger-scale group, where 33.3% of samples were *S. aureus* positive.

### 5.3.10 Regression analysis

Freezing time was treated as a continuous predictor variable for a simple logistic regression analysis for the outcome of finding any contamination, which was used to determine a small, trend-level (p=0.08) increase in the odds of finding any contamination with a one-day increase in freezing time (OR 1.02, 95% CI: 0.99-1.04). This value was lower (OR 1.01, 95% CI: 0.99-1.02) and the association was weaker (p=0.14) when the microbial outcome was limited to CPS-positive samples. When 10-day increases in freezing time were used to create an ordinal predictor variable for recovery of any target microorganisms, there were only slight changes to the observed association (OR 1.04, 95% CI: 0.94-2.09) and the association remained at a trend-level of significance using an α=0.05 (p=0.09). When 30-day increases in freezing time was used as an ordinal predictor variable for the same outcome, a stronger signal (OR 1.86, 95% CI: 0.82-4.17) indicating increased odds of detecting of target pathogens with each 30-day increase in freezing time was observed, but this association remained at a trend-level of significance using an α=0.05 (p=0.09).

Likelihood of CPS-positive contamination on poultry samples purchased from retailers using on-farm processing facilities compared to samples from retailers who process poultry using a
third party was assessed using simple logistic regression with on-farm processing as a binary predictor variable for CPS contamination, the resulting coefficient did not approach statistical significance \((p=0.72)\). The same relationship was evaluated using a Fisher’s Exact Test, which also did not approach statistical significance \((p=0.69)\). These same tests were repeated with outcomes for \textit{E. coli} contamination, contamination with any target species and for any contamination, none of which yielded statistically significant results. Other binary and categorical predictors of microbial outcomes including antimicrobial usage, scale of yearly production (≥1000 birds/yr or <1000 birds/yr), and USDA/MDA were evaluated using simple and multiple logistic regression and Fisher’s Exact Tests. In models adjusted for annual production volume and on-farm versus third-party processing, MDA-certified processing facilities were less likely than those without certification to have \textit{S. aureus} isolated from the purchased poultry product; however this estimate of association was not statistically significant \([OR 0.43, 95\% CI 0.1, 1.8, p=0.26]\).

5.4 Discussion

5.4.1 Microbial results: antimicrobial resistance phenotypes

The absence of MDR \textit{E. coli} or \textit{S. aureus} and the infrequent recovery of isolates displaying resistance to more than one class of antimicrobials are findings of particular public health significance. The low rates and low diversity of AMR phenotypes that were observed could represent “background resistance,” \textit{i.e.} resistance genes that are distributed widely between many bacterial populations over long periods of time. It is unlikely that these rare observed instances of AMR phenotypes are the result of genes recently acquired through selective pressure in the microbiome of the on-farm environment. Background resistance genes may have been circulating for many thousands of years, and may predate the modern selective pressure of human antibiotic usage [32].
These results are supporting evidence for the hypothesis that some of the characteristics of Maryland direct-market poultry producers that depart from the conventional/industrial paradigm of high density poultry livestock production and routine antibiotic inputs may impact the risks of microbial contamination of consumer poultry meat products with MDR foodborne pathogens. Cases of foodborne illness and livestock-origin infections complicated by high levels of pathogenic drug-resistance are far less frequent than those without such complications. However, these illnesses and infections are far more serious, costly, lengthy, and result more frequently in hospitalization, extended need for clinical care and death [4]. A microbiome is an ecological community of microorganisms and their genetic material within any given environment niche or system. The potential for antimicrobial-resistance genes to develop within the microbiome of conventional livestock production systems and disseminate into other the microbiome of other human environments is a serious threat to global public health. Alternative models to industrial food animal production need to be explored and evaluated for their potential to produce livestock in a manner that does not contribute to the global burden of drug-resistant pathogens and AMR genes in the human environment. This research is only a preliminary step in exploring some alternatives to the conventions of industrial scale poultry production. However, these discoveries provide important groundwork for focusing on new research questions and targeted areas for inquiry within and beyond the Maryland direct-market poultry supply chain to establish the validity of these findings and expand on the conclusions drawn from this research.

5.4.2 Prevalence of S. aureus and CPS

The 30% and 32.5% prevalence of S. aureus and CPS in this market-basket sample of Maryland direct-market retail poultry is in keeping with the trends observed in the few market-basket studies assessing the industrial poultry supply chain for these outcomes. These
findings indicate that CPS contamination of consumer poultry meat products is likely to still be a relevant food safety concern for direct-market poultry production. However, the absence of MDR *S. aureus* and CPS in direct market samples may present an important difference in the overall food safety health risks associated with this direct-market supply chain compared to what has been reported from products associated with a conventional supply chain. The risks of food or livestock-origin MDR CPS colonization and/or infection associated with consumer exposure may be substantially different for these products than for consumer poultry meat products from the industrial supply chain.

However, without better data collection on *S. aureus*, MDR-SA and MRSA prevalence (under NARMS and in other food safety research) and associated human illness and infections (in FoodNet and other health surveillance programs and research) for both the direct-market and industrial food animal supply chains, this assumption is impossible to verify. Previous research on these issues has already advocated for increased surveillance for and reporting of MSSA, MRSA and MDR-SA in the US food system [20]. This research provides additional evidence for that recommendation, and further indicates that statewide direct-market supply chains for poultry and other food animal products should also be included in the sampling strategy employed by the NARMS retail meat surveillance program.

### 5.4.3 Prevalence of *Salmonella* spp.

The absence of *Salmonella* positive isolates among the 40 poultry samples is unexpected. In our study design, we anticipated a 20-30% prevalence of *Salmonella* in our sample pool. We have high confidence in the internal validity of our laboratory method, as it was adapted from the standard literature and all QC-positive controls grew culture-positive *Salmonella* isolates when cultured through our protocol. However, we do not necessarily conclude that
the negative results indicate a total absence of viable *Salmonella* on these samples or within this supply chain. Three possibilities exist that we can identify based on the available information: (1) Some combination of factors related to lower overall concentrations of *Salmonella* in poultry livestock pre-slaughter; effective prevention, decontamination and control of microbial cross-contamination during slaughter and processing; and long-term freezing of poultry products actually leads to a large reduction in the viable number of *Salmonella* on consumer products that can be recovered through selective enrichment media. In this case, this reduction would put the number of viable *Salmonella* below the LOD of the methods used in this study. (2) Long-term freezing alone at the duration and holding temperatures used by commercial poultry processors reduces the viable number of *Salmonella* that can be recovered using standard methods. Other differential factors may play a minor, if any, role in observed *Salmonella* reduction; long-term freezing reduces survival of viable *Salmonella* isolates below the LOD of the method. (3) Viable and potentially infectious *Salmonella* isolates actually are present above the method LOD on frozen samples, but are injured or metabolically damaged in some way by long-term freezing and thus do not grow or present as typical *Salmonella* on selective culture media.

Under the first two possibilities, the risk of contamination of consumer products with *Salmonella*, and the concurrent risks of human exposure through food resulting in increased risks of *Salmonellosis* to the consuming population, would be lower in the direct-market poultry supply chain compared to the industrial market for these products. These scenarios highlight the need for focused inquiries and further research to determine the roles and relationships of particular factors typical to the Maryland direct-market supply chain (most notably long-term freezing of poultry products) on these outcomes. Risks for positive
Salmonella contamination of the fresh poultry meat products that are sold within this supply chain may be substantially different under either of these circumstances.

In the third scenario, structurally or metabolically injured Salmonella that are still capable of reproduction and human pathogenicity are being read as false-negatives on the culture protocols employed for this research. Under these circumstances, the effects of long-term freezing actually decreases the sensitivity of the culture-based testing methods in use. This is certainly a possibility, and if true, may influence the observed outcomes in synergistic or antagonistic relationships with either, both, or neither of the other two possible scenarios in addition to other unknown factors. Resampling meat products within this population and from this supply chain using a variety of non-selective media and selective enrichment protocols would help to establish the extent and validity of this possible third scenario for the absence of culture-positive Salmonella in the sample pool.

Some recent scientific research provides some evidentiary support for the likelihood of the first scenario, in which a variety of co-factors, possibly including long-term freezing, contribute to the surprisingly low prevalence of Salmonella isolates. A presented, but as-yet unpublished, study from Canada found lower concentrations and prevalence of susceptible and resistant Salmonella from the ceca of processed broiler poultry from small-scale poultry operations in Ontario than what typically has been observed in samples taken from freshly-killed poultry carcasses in the industrial supply chain [33].

5.4.4 Prevalence of E. coli

E. coli detection does not necessarily indicate the presence of a human pathogen. Discovery of E. coli isolates on 22.5% of poultry samples does not indicate that pathogenic bacteria are necessarily present, but rather indicate an increased likelihood of the presence of some kind
of fecal-origin Gram-negative contamination. The rates of *E. coli* contamination are substantially lower than those reported in NARMS and in other research literature. This may indicate a difference in actual food safety risks for consumers of these direct-market products to be infected with fecal-origin bacterial contaminants, but more research needs to be performed to establish the validity of those findings. As with *Salmonella*, freezing may play a role in reduction of *E. coli* that can be recovered using these methods.

One limitation of this study is that we did not conduct serovar analysis of *E. coli* isolates or collect other data which could be used to determine pathogenicity. All positive isolates were preserved in -80°C microbank tubes, and can be evaluated more fully at a later date.

5.4.5 *Non-target microorganisms (non-CPS)*

Recovery of a variety of non-target microorganisms including CNS species and a variety of Gram-negative bacteria, including human and animal pathogens, is unsurprising, and provides some potentially interesting concepts for further research in this supply chain. The two species of CNS, *S. warneri* and *S. simulans* are both animal-associated and, like most CNS, are thought to rarely cause disease in humans, though *S. warneri* has been suspected as a potential cause of both bovine and human spontaneous abortions [34].

That many of the Gram-negative non-target species were resistant to several classes of antimicrobials is not a specific cause for concern for the issue of livestock-origin antimicrobial resistance, as the patterns of resistance observed are intrinsically associated with these bacterial species. These species do not readily disseminate their resistance genes into the microbiome through horizontal gene transfer (HGT). Their resistance genes are not located on the same highly mobile plasmids and gene cassettes that are the hallmark of microbial sharing of AMR genes within the microbiome of food animal production.
The finding of these non-target species on poultry products may be of interest for future public health research. As little is known about microbial food safety risks, it is reasonable to presume that other foodborne microorganisms apart from the standard pathogens associated with food safety risks in industrial-scale poultry systems may potentially be a part of the food safety risk paradigm for the direct-market poultry supply chain. This handful of organisms (all of which were recovered from the *Salmonella* lactose-broth rinsate protocol or the *E. coli* culture protocol and species confirmed using the BD Phoenix system) may represent some of the microorganisms that are intrinsic to the food safety microbiome of direct-market poultry systems. All of the non-target gram-negative isolate species have the potential to be human pathogens. However, these findings should not be interpreted as having any specific relevance to food safety risks in this supply chain.

5.4.6 Effect of long-term freezing on pathogen recovery

Analysis of in-depth interviews with Maryland poultry farmers determined that the large majority of poultry meat products retailed in this supply chain were sold frozen. Depending on the operation, between 75-100% of their direct-market poultry meat sales were reported to be of frozen products. Often, these products were reported to be sold after being frozen for several weeks. Standard industrial supply chain poultry and meat products are generally sold fresh, and are not frozen as a standard practice of the typical industrial-scale processing or distribution systems. The effects of long-term and short-term commercial freezing on the microbial status of meat products has not been clearly established, particularly for non-typhoidal *Salmonella* spp. Research has previously described survival of different *Salmonella* species in a wide variety of meat matrices and niche environments, including samples that are frozen for different amounts of time, and held frozen and thawed at different temperatures to assess microbial attrition [36, 37, 38, 39, 40, 41]. Between these different
studies, varying levels of injury, inactivation, and attrition of different *Salmonella* species and serovars ranging from 100% survival to full attrition have been reported. The factors related to survival and recovery of viable *Salmonella* spp. in frozen poultry meat products are unclear.

Viable *S. aureus* and *E. coli* O157:H7 isolates have both been demonstrated in experimental studies to survive and reproduce after freezing in poultry meat [41] as well as pork products [42] with *E. coli* generally experiencing higher rates of attrition than *S. aureus*. A recent study indicated that both MRSA and MSSA are capable of the same kind of biofilm formation that is one of the key microbial resources thought to be important in determining environmental hardiness and microbial survival rates when challenged by temperature abuse, including freezing. The same study also demonstrated that MSSA, MRSA, and a variety of *S. aureus* subtypes are capable of coexisting without antagonism and even with possible synergistic effects among different *S. aureus* subtypes [43]. A study of STEC *E. coli* under laboratory conditions demonstrated that short-term freezing (5 days at 20°C) did not dramatically reduce microbial viability, survival, or virulence, but that repeated freeze-thaw cycles significantly reduced survival rates of STEC *E. coli* but did not impact virulence factors [44]. Another recent study of STEC and non- STEC *E. coli* in ground beef demonstrated that short-term (5 days) and long term (75 days) freezing at 20°C induced a small but statistically significant reduction in concentration of all *E. coli* serotypes, including O157:H7 (< 1 log reduction CFU/ml). Furthermore, the study demonstrated that viable *E. coli* O157:H7 isolates not only survived freezing and thawing, but were able to survive at levels far above the known infectious dose for humans after cooking the meat in a pan or oven broiler to an internal temperature of 70°C. The study further demonstrated that long-term freezing may
have even enhanced the capacity of *E. coli* O157:H7 in beef patties to survive cooking and high temperature abuse [45].

Though the research evidence is inconclusive and incomplete, it is possible that the effects of long-term freezing of the products sampled in this study are solely contribute to the low prevalence of MDR and drug-resistant target pathogens observed. There is a possibility for differing survival rates of viable AMR and susceptible pathogens during long-term freezing, or for the loss of AMR activity after freezing and thawing of microorganisms. Effects of long-term freezing could also potentially be responsible to an unknown degree for the absence of detectable *Salmonella*. The potential for these scenarios should be explored in future research.

5.4.7 Strengths, limitations and areas for further research

This study benefits from a wealth of information implicitly integrated into the study design and explicitly used to contextualize, interpret and test the market-basket data that was generated in this research. Without the knowledge and data obtained through the in-depth interviews and the survey responses used to describe this novel environment, potentially important public health findings, such as the absence of MDR target pathogens, would be more difficult to explain in context. Our overall confidence in the external validity of the findings of this study, as well as our ability to analyze its public health significance, are strengthened by the context provided by our previous research. A specific strength provided by this context is the knowledge that our market-basket sample includes a representative majority of the eligible commercial population in the state during the time when the study was performed, sampling 40 of an estimated study population of ~66 commercial direct-market poultry producers statewide. By sampling over 60% of the identified study
population, we are able to generalize (within limits) observed prevalence trends to the statewide population of poultry producers. Even if the estimate of n~66 is off by as much as 50%, our market-basket sample would still be represent greater than 40% of the target population.

This study has several limitations. While our market-basket sample size is representative of the study population, a sample size of 40 limits options for multiple logistic regression analysis to describe statistically significant associations and relationships. The absence of statistical significance for any of these tests should not be interpreted as evidence for a lack of a relationship. Rather, exploring these relationships will require larger sample sizes, repeated measures, more diverse sampling sites and sample types, and other data collection strategies. Further, conducting a risk factor analysis was not the explicit purpose of this research. Rather, we hoped to describe food safety trends at the supply chain level, and also describe unexplored and undocumented factors which may be relevant to food safety outcomes and useful for public health research. The purpose and the public health significance of this research is in providing the groundwork for targeted future investigations into the still largely-unexplored food environment of direct-market systems for poultry and other agricultural products.

It is important to recognize that this cross-sectional analysis represents a snapshot of a dynamic and an adaptive system. Many of the factors that were described in this population are in constant motion and evolution, both in terms of human activity and changes within the food safety microbiome of this supply chain environment. We have high confidence that the data presented in this study accurately describe a representative sample of the study population at the time when this research was conducted. However, more diverse sampling
strategies and repeated measures taken over different time intervals are necessary to maintain accurate sources of relevant data and to develop a broader and more in-depth understanding of how changes in this supply chain that develop or cycle over time may affect microbial food safety outcomes.

Directions for future research are diverse and abundant in exploring microbial food safety issues in Maryland’s direct-market poultry supply chain and in other direct-market agriculture systems. Building on the data already obtained and analyzed from this study population is a research opportunity, since, to the best of our knowledge, no other statewide poultry supply chain has been characterized to the same degree. Within this study population, next steps for future research should include a comparable microbial analysis of matched fresh and frozen chicken meat samples from the same vendor, samples could also be matched to the same processor and processing day. This data will help to evaluate the differential effects of long-term freezing storage practices on the microbial status of direct-market poultry meat.

Experimental studies could also help to assess the effects of long-term freezing on microbial recovery on selective and nonselective culture media. Additional next steps in this study population should include an attempt to gather multiple market-basket poultry samples from the same vendor, particularly over an entire season of poultry production and multiple processing events. This research will help to provide higher-resolution data for characterizing farm-level or group-level variables’ relationships with microbial food safety outcomes. Other common poultry-associated foodborne pathogens should also be sampled within this study population to establish their prevalence and AMR characteristics, including Enterococcus and Campylobacter. This research will help to fill in more information relevant to food safety in direct-market poultry systems and will enable enhanced comparison with the NARMS surveillance of industrial poultry meat. Genetic testing of the isolates obtained in
this research as well as from new market-basket samples from Maryland and other statewide poultry supply chains will generate data that can be used to assess the prevalence, mobility, and, epidemiology, and origins of microbial genes coding for virulence, antimicrobial resistance, and other relevant genes in the microbiome associated with direct-market poultry systems.

Comparable research should also be carried out in other statewide direct-market supply chains for poultry and other products. While some findings from this study may be generalizable to some other states’ supply chains, this cannot be accurately measured in lieu of richer data sources from other states. States inside and outside of the Mid-Atlantic region should be tested to establish the validity of a regional effect to any of the observed outcomes.

These data are applicable to public health research in several ways. Most significantly, this study, in conjunction with the other research performed on the Maryland direct-market poultry supply chain, begins to fill in the knowledge gap on food safety issues in direct-market poultry systems. Additionally, this study provides the necessary groundwork to develop targeted research questions for building upon the analyses performed here and continuing to efficiently closing this research gap.

These findings are also relevant for policy and regulatory stakeholders with a mandate to protect food safety and reduce consumer food safety risks in the Maryland and other statewide direct-market supply chains for poultry and other agricultural products. Particularly for states charged with regulating food safety in direct-market poultry retail, this analysis provides some of preliminary information and data for developing an evidence-based strategy for developing policy and regulation to control food safety risks in direct-market
agricultural systems for poultry and other food animal products. More in-depth data collection and analysis should be conducted to expand the body of research that will be required to develop and implement science-based and data-driven policy and regulation on these important issues.

5.5 Acknowledgments

I would like to acknowledge Dr. Meghan Davis for her comments and proofreading of this manuscript as well as for her input with interpreting the microbial results. Dr. Marie Diener-West also provided particular insight into the statistical analyses and tests that were used to analyze the data. The Davis Lab group also generously allowed me to use their laboratory space to perform culture analysis of retail meat samples. Karen Carroll’s lab group at the Johns Hopkins Hospital Clinical Microbiology Diagnostics Laboratory performed the specimen identification and antimicrobial-susceptibility analysis using the BD Phoenix automated system. The CLF Maryland Food System Mapping team created the figure showing the geographic distribution of participating poultry retailers (Figure 5-1).
5.6 References


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Figure 5-1: Locations of Participating Direct-Market Poultry Retailers (N=40)
Figure 5-2: Distribution of Time Spent Frozen for Poultry Products (N=30)

*The standard normal curve is added for emphasis and is not an actual trend line fitted to the distribution.
Table 5-1: Prevalence of AMR *S. aureus* and *E. coli* Isolates by Processor Location (on-farm vs. third party facility) and Food Safety Agency Inspection Status

<table>
<thead>
<tr>
<th>Processor Type</th>
<th><em>S. aureus</em></th>
<th><em>S. aureus</em>: 1+ Classes AMR</th>
<th><em>S. aureus</em>: 2 Classes AMR</th>
<th><em>E. coli</em></th>
<th><em>E. coli</em>: 1 Class AMR</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Processors (n=40)</td>
<td>12/40 (30.0%)</td>
<td>6/40 (15.0%)</td>
<td>1/40 (2.5%)</td>
<td>9/40 (22.5%)</td>
<td>2/40 (5.0%)</td>
</tr>
<tr>
<td>3rd Party* (n=15)</td>
<td>5/15 (33.3%)</td>
<td>2/15 (13.3%)</td>
<td>1/15 (6.7%)</td>
<td>4/15 (26.7%)</td>
<td>1/15 (6.7%)</td>
</tr>
<tr>
<td>OFPP: All* (n=25)</td>
<td>7/25 (28.0%)</td>
<td>4/25 (16.0%)</td>
<td>0/25</td>
<td>5/25 (20.0%)</td>
<td>1/25 (4.0%)</td>
</tr>
<tr>
<td>OFPP: MDA/USDA* (n=19)</td>
<td>5/19 (21.1%)</td>
<td>3/19 (15.8%)</td>
<td>0/19</td>
<td>5/19 (26.3%)</td>
<td>1/19 (5.3%)</td>
</tr>
<tr>
<td>OFPP: Uncertified* (n=6)</td>
<td>2/6 (33.3%)</td>
<td>1/6 (16.7%)</td>
<td>0/6</td>
<td>0/6</td>
<td>0/6</td>
</tr>
</tbody>
</table>

* Vendors using a third party poultry processor; †: All on-farm poultry processors (OFPP); ‡: OFPP certified and by USDA(N=1) or MDA(N=18); §: OFPP not certified by either/any agency;
Table 5-2: Species ID and AMR Phenotypes of “Double Hit” Samples (N=6)

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Gram-Positive Species ID</th>
<th>Gram-Positive AMR</th>
<th>Gram-Negative Species ID</th>
<th>Gram-Negative AMR</th>
</tr>
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<tbody>
<tr>
<td>I</td>
<td><em>S. aureus</em></td>
<td>None</td>
<td><em>K. oxytoca</em></td>
<td>Ampicillin*</td>
</tr>
<tr>
<td>K</td>
<td><em>S. aureus</em></td>
<td>Tetracycline</td>
<td><em>E. coli</em></td>
<td>Tetracycline</td>
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<tr>
<td>M</td>
<td><em>S. simulans</em></td>
<td>None</td>
<td><em>E. coli</em></td>
<td>None</td>
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<tr>
<td>O</td>
<td><em>S. aureus</em></td>
<td>Ampicillin, Penicillin</td>
<td><em>E. coli</em></td>
<td>None</td>
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<td>U</td>
<td><em>S. aureus</em></td>
<td>None</td>
<td><em>E. coli</em></td>
<td>None</td>
</tr>
<tr>
<td>HH</td>
<td><em>S. aureus</em></td>
<td>Ampicillin, Penicillin</td>
<td><em>E. coli</em></td>
<td>Imipenem</td>
</tr>
</tbody>
</table>

*Klebsiella oxytoca is intrinsically resistant to ampicillin*
Table 5-3: Antimicrobial Resistance Patterns Among CPS-positive Isolates (N=13)

<table>
<thead>
<tr>
<th>CPS+ Samples</th>
<th>AMP</th>
<th>FOX</th>
<th>CLIN</th>
<th>DAP</th>
<th>ERM</th>
<th>GEN</th>
<th>LZD</th>
<th>MIN</th>
<th>MOX</th>
<th>NIT</th>
<th>OXA</th>
<th>PEN</th>
<th>QPN-DAL</th>
<th>RIF</th>
<th>S TP</th>
<th>TET</th>
<th>TMP-SUL</th>
<th>VAN</th>
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AMP: ampicillin; FOX: cefoxitin; CLIN: clindamycin; DAP: daptomycin; ERM: erythromycin; GEN: gentamicin; LZD: linezolid; MIN: minocycline; MOX: moxifloxacin; NIT: nitrofurantoin; OXA: oxacillin; PEN: penicillin; QPN-DAL: quinupristin-dalfopristin; RIF: rifampin; STP: streptomycin; TET: tetracycline; TMP-SUL: Trimethoprim-Sulfamethoxazole; VAN: vancomycin

*Sample “X”: Phoenix specimen ID as S. intermedius
Chapter Six

Conclusions
6.1 Applications for public health research

To the best of my knowledge, the research included in this dissertation thesis represents one of the only attempts in the existing scientific literature to describe the functional aspects of all stages of the direct-market broiler poultry supply chain. Furthermore, these are the first studies to apply a research lens of microbial food safety to any qualitative or survey-based quantitative analysis of this niche environment of the US food supply chain. Apart from the single other market-basket study carried out in Pennsylvania, which did not include any analysis of antimicrobial resistance outcomes, this is (again, to the best of my knowledge) the only study to generate actual market-basket data to begin to explore the food safety issues for this route of consumer population exposure in the direct-market poultry supply chain. These analyses contribute to filling in the large research gap surrounding issues of food safety in direct-market supply chain for broiler poultry. To a lesser extent, these analyses may also contribute to filling in the research gap surrounding food safety issues associated with other potentially high-risk food animal products sold in direct-to-consumer supply chains.

Given the rapid expansion of these niche consumer markets, there is a critical need for more information based on scientific research in order to more fully characterize the risks for population exposure to livestock-origin antimicrobial-susceptible and AMR microbial pathogens. This exploratory research does not fulfill the requirements for actionable working knowledge to perform an informed risk assessment for these exposures, and did not set out to do so per se. Rather, this research aimed to describe and analyze differences between direct-market systems for commercial production, processing and distribution of broiler poultry and their industrial-scale counterpart from a microbial food safety perspective. Our analyses demonstrated that many of these inter-supply chain differences may have the potential to contribute to different microbial food safety outcomes, particularly with regard
to the prevalence of MDR foodborne pathogens. Finally, the market-basket analysis demonstrated that MDR strains of three common poultry-associated foodborne pathogens were absent from a representative sample of the statewide direct-market poultry supply chain. The market-basket analysis also produced the unexpected results of no positive *Salmonella* isolates and lower prevalence of *E. coli* (than results observed in recent NARMS surveillance) recovered from raw frozen poultry samples. Several theories and hypotheses are outlined to explain these results using the context obtained from in-depth interview data and the responses to the survey questionnaire.

These results and analysis lay the groundwork for developing research questions and areas of investigation that build on the findings of this dissertation research. Testing and building evidence to support or refute these theories and hypotheses, along with designing research studies to assess the validity and generalizability of our findings within and beyond the Maryland direct-market poultry supply chain represents some of the future research directions enabled by this dissertation. The analysis produced in this study and in future research will be important in developing an informed risk framework for analyzing and controlling microbial food safety risks in direct-market broiler poultry and other comparable supply chains.

However, beyond enabling more focused public health inquiries directed towards food safety issues, this dissertation research contributes to filling in a broader, and arguably even more critical knowledge gap for public health research: the epidemiology of livestock-associated antimicrobial resistance within the microbiome of zoonotic bacteria in an underexplored niche of the US food supply chain. The total absence of MDR *E. coli* or *S. aureus* recovered from a representative cross-sectional market-basket sample of the statewide supply chain is a
strong indicator that some factors differentiating direct-market and industrial-scale poultry production may contribute to lower prevalence of MDR pathogens on consumer meat products, and potentially also at other “upstream” stages of the supply chain (on farm and during processing, storage and distribution). These findings indicate that the alternative models used in Maryland for small-scale commercial poultry farming may potentially contribute to a dramatically different population exposure paradigm and subsequent disease burden risk for human infection and illness caused by livestock-associated MDR pathogenic bacteria. These analyses must be repeated in the same supply chain and other comparable environments to further establish the potential for human exposure to these pathogens through the direct-market agriculture supply chain for food animal products. Additional exposure modeling for the routes by which indirect (i.e. not through direct consumption of contaminated food or direct contact with livestock) population exposures to these agents may potentially occur via the direct-market agriculture supply chain is another important next research direction.

These findings and the larger context of the existing literature on antimicrobial resistance of food-producing animal origin point to a distinct need to evaluate the origins, extent, drivers and directionality of the on- and off-farm transportation and environmental fate of AMR bacteria and genetic material recovered from all stages the direct-market supply chain. Occupational exposures to livestock-origin pathogens, including evaluations of worker colonization and infection, as well as the household environments (often located on the farm itself), family members, volunteers, farm visitors and community contacts of farmers and their families are an important area for directed research. Environmental sampling and analysis for evaluating the variety, prevalence, concentration and distribution of AMR bacteria and genetic material recovered from live poultry and non-poultry livestock,
companion animals, wildlife, and on- and off- farm environmental and ecological matrices are other critical areas for future research to fill in this knowledge gap.

Attempting to characterize the complex, evolving nature of antimicrobial resistance within the dynamic environments of the small-sale commercial supply chain for poultry and other agricultural products requires a multidisciplinary approach. This research demonstrates the applicability of such an approach and the manner in which that disparate types of data can be integrated to strengthen the overall study design and enhance the ability for researchers to contextualize and interpret scientific findings. This research model can be duplicated or adapted to conduct exploratory research in other, comparable environments to further fill in the research gaps for the relevant public health issues. These strategies may be applied in a more limited scope to conduct directed research in food safety risk assessment and exposure analysis, or through a broader lens to future observational studies exploring the epidemiology of AMR bacterial populations and genetic material in niche environments of the US food system.

Understanding the intrinsic factors in alternative food animal production systems that may generate different selective pressure (from the current trends observed in the highly standardized industrial system) for pathogenic and non-pathogenic bacteria in these environments to acquire and disseminate AMR genes is an important emerging area of public health research. The current system that produces the vast majority of food animal products in the US food supply requires massive antimicrobial inputs. The total antimicrobial inputs for growth promotion, prophylaxis, and for therapeutic veterinary treatment of livestock animals in the US in 2007 accounted for ~13 million kg., or roughly ~80% of the total antimicrobial usage in the US [1]. The poultry production models
described in this study frequently did not employ any antimicrobial inputs at all; the minority that did generally operated under a different paradigm for usage of these drugs. Uncovering the extent to which the practices and models used in alternative food animal production models individually and collectively may contribute to an alternative paradigm for the incubation and dissemination of MDR livestock-associated zoonotic bacteria in the food supply chain may be destined to become an important emerging and future area for public health research.

Stemming the rising tide of global antimicrobial resistance for infectious diseases in the healthcare, community, and food system environments has already become one of the predominant public health issues of the 21st Century. The World Health Organization (WHO) described in their recent report that “...a post-antibiotic era – in which common infections and minor injuries can kill – far from being an apocalyptic fantasy, is instead a very real possibility for the 21st Century.” [2]. The executive branch of the White House recently released their National Strategy for Combating Antibiotic-Resistant Bacteria (CARB), with ambitious targets to dramatically reduce disease incidence rates for drug-resistant infections by 2020. Their plan specifically highlights program goals for “...improved antibiotic stewardship in healthcare settings, prevention of the spread of drug-resistant threats, elimination of the use of medically-important antibiotics for growth promotion in food animals, and expanded surveillance for drug-resistant bacteria in humans and animals...”[3]. The FDA, USDA and CDC are all currently updating and expanding efforts to monitor and reduce the incidence of antimicrobial resistance in response to the White House announcement of the CARB plan.
It is entirely possible that research into alternative models for food animal production that do not contribute to the global emergence of MDR bacteria will move off the margins of scientific inquiry and become a much higher priority for policymakers and public health researchers. The findings of this dissertation, while exploratory and not designed to carry out a quantitative risk assessment or solely inform science-based policy, represent an important first step in this emerging research area.

6.2 Applications for policymakers

Federal policies in the US on many relevant issues are changing as understanding and combating antimicrobial resistance becomes a higher priority for policymakers. Future research in alternative food animal production systems can target the priorities of these policy stakeholders to generate directed research for the purpose of enhance data-driven policy and regulation on these large, complex issues as they relate to the US food system.

In a more narrow application, statewide food safety policymakers, particularly the administrators of the MDA’s voluntary certification program and of other states’ regulation governing food safety in FSIS-exempt poultry agriculture can directly apply the analyses pertaining directly to perceptions on policy and governance as well as the quantitative results and analysis. In the absence of reliable research defining microbial food safety risks in the direct-market poultry supply chain, the perspectives on these issues held by individuals with professional knowledge and experience can provide valuable insight to inform further investigations about this growing supply chain which can be used to form data-driven food safety policies. Information on this population’s attitudes and opinions towards government agencies generally, as well as pertaining to specific relevant policies and regulation, can be applied to restructure policy (and the presentation of the policy) to be less threatening and
more approachable for the target population. These changes can be used by policymakers to increase enrollment, adherence and compliance with their food safety policies or programs.

The interview and questionnaire data on the concepts and perspectives related to food safety as well as the food safety risk management practices and strategies used in small-scale commercial poultry production and processing can also be of use to policymakers. Many interview participants complained that policymakers generally crafted ill-fitting and ineffective regulation resulting from their lack of understanding and background in the needs, values and constraints of direct-market farmers and small-scale, diversified agriculture. The data can be used as a starting point for crafting regulation that is responsive to the realities of small, direct-market farmers by incorporating their viewpoints and understanding the large and small contrasts that set this supply chain apart from its industrial-scale counterpart. The findings and analyses from this research could be used in tandem with more in-depth and far-reaching investigations of microbial outcomes and factors relevant to food safety at all stages of the direct-market poultry supply chain to develop regulatory strategies that employ elements of food safety risk management practices and strategies already used by this commercial population to more efficiently reduce consumer food safety risks.

The microbial data, while statistically representative of the statewide supply chain and highly applicable in guiding future public health research, is inadequate in isolation to be applied to calculating population exposure risks or generating data-driven food safety policy, even when the findings are only generalized to apply to Maryland’s food safety policies governing direct-market poultry systems. However, partnerships with agency stakeholders to enhance collaboration and direct research toward policymaking priorities in and beyond Maryland should be established to add to the findings presented in this exploratory, cross-sectional
market-basket study. With more robust microbial food safety data generated from future directed observational epidemiology research, these findings could be coupled with a deeper understanding in the research literature of the intrinsic factors of small-scale direct-market poultry production related to food safety to inform and statistically power a risk factor analysis for estimating population exposure and food safety health hazards in these alternative models and retail systems. Data-driven policy for assessing and controlling microbial food safety consumer risk issues in direct-market supply chains for poultry could be informed (and potentially extrapolated to other comparable direct-market agriculture systems) by such a risk factor analysis.

6.3 Limitations and areas for future research

The primary limitation of this research is the cross-sectional study design, which offers only a snapshot of a highly dynamic and complex system. The microbial outcome data, being based on two highly dynamic systems (the evolving supply chain environment and the highly complex and adaptive systems of the microbiome) is the most subject to these limitations. These limitations are partially due to the inherently exploratory nature of this research endeavor, and partially due to resource constraints. Evaluations of causality between the distribution of factors identified in the survey questionnaire and the microbial outcome data are limited by this cross-sectional study design. Future research will need to replicate and expand on these findings in this environment and study population as well in other comparable niche environments to establish causality. Longitudinal studies focusing on different windows of time, including more frequent microbial sampling of livestock and the on-farm production and processing environment, repeat sampling of the same environments, and drawing market-basket samples in tandem and at different time intervals from the same operation will be required to further characterize the relationships between
different models and practices associated with direct-market poultry systems and human exposure to livestock-origin MDR, AMR and drug-susceptible zoonotic and foodborne microbial pathogens.

A further limitation to the microbial data was the decision to focus on culturable isolates recovered from frozen samples. The effects of the long-term freezing may have affected recovery rates for culture-based methods, particularly for selective media based culture of *Salmonella*. These results may be substantially different for fresh, unfrozen poultry products; this particular issue needs to be evaluated in future research. The unexpectedly low prevalence of *Salmonella* and possibly, to a lesser extent, *E. coli*, may represent an issue with the LOD for the culture-based methods used in this study. Different culture-based recovery methods using non-selective media may have different LODs and relative sensitivity for recovery of target microorganisms. Laboratory studies to evaluate the recovery rates of different selective and nonselective culture-based methods for recovery of *Salmonella*, *E. coli*, *Campylobacter* and other relevant target microorganisms. While using culture-based methods adapted from the research literature increases the comparability of our microbial data, and purchasing frozen samples represents the typical and most relevant consumer exposure to study in exploratory research, these strategies may have failed to capture hard-to-culture bacteria, nonviable specimens, and species or strains (including AMR or MDR strains) that are differentially affected in terms of survival and recovery of target microorganisms isolated from frozen chicken meat samples using these methods. These issues should be further explored in laboratory studies using a variety of culture-based and culture-independent methods.
This research lacked the resources to perform serogroup, serotype and subtype analysis of culture-positive and BD Phoenix-confirmed isolates. This data could have enabled more refined analysis of the specific microorganisms that were recovered from this supply chain analysis, including information that could determine whether they were truly livestock-origin species, or possibly from a human origin or reservoir. Positive isolates were archived in microbank tubes in a -80°C laboratory freezer, and are available for genetic analysis. This analysis and other future microbial exposure assessments of direct-market poultry supply chains that perform serogroup, serotype and subtype analysis can be used to develop a more refined picture of the microbiome associated with this environmental niche.

Generally, these limitations are all a product of exploratory research in a novel environment. This research only begins the work of applying a scientific research lens to understanding and characterizing the relationships and important research questions for exploring these issues in this niche of the US food supply chain.

This dissertation research was a fascinating and enriching experience for me on many different but inextricable levels. I connected with and learned from an intriguing population of women and men engaged in a unique profession and lifestyle. Their insights were a foundation for carrying out groundbreaking scientific research within a variety of disciplines. On a personal level, the experience of working in partnership with a community to achieve mutually beneficial goals for public health and science has shaped my own ideas and feelings on the practice of community-based participatory public health practice and research. In the process of performing research to define and fill in important knowledge gaps for public health in the US food system, I grew as a scientist and as a person. I am grateful for all the present and future opportunities to continue this work, which has only just begun, and
which I expect to last longer than my career. The theologian and ethicist Reinhold Niebuhr once wrote:

“Nothing that is worth doing can be achieved in our lifetimes, therefore we must be saved by hope. Nothing which is true or beautiful or good makes complete sense in any immediate context of history, therefore we must be saved by faith.” [4]

Topics of hope and faith do not frequently enter into the conclusion of PhD dissertations in the sciences. However, hope and faith or the kind described above are the context in which the accumulated knowledge draws deeper meaning. This is not because any particular goals have been or will be achieved by any single action or even over an entire individual career or lifetime. It is because the process itself is imbued with intrinsic and holistic meaning: the belief (not certain knowledge) that we are always acting as part of a larger effort to do something worthwhile and good. In this, I am privileged and grateful to continue to play my role.
6.4 References


7.1 Appendices

Appendix A: Databases used to estimate population N

MDA Rabbit and Poultry On-Farm Processing Certified Vendors Online List (October 2014)
MDA Marketing Office: “Maryland’s Best” Online Directory
Eat Wild: Maryland Pastured Poultry Products Directory
Southern Maryland Meats: Online Directory of Farms and Producers
Local Eastern Shore Sustainable Organic Food Network Directory
CLF Maryland Food System Map
LocalHarvest Maryland Directory
Frederick County Virtual Farmers’ Market
Montgomery County Farm Directory
Farmer’s Pal: Maryland Organic and Sustainable Meat Farms Directory
Future Harvest/Chesapeake Area Sustainable Agriculture: “Amazing Grazing” Directory
FreshFarm Markets: “Meet Our Producers” Database
USDA ATTRA (National Sustainable Agriculture Information Service): Maryland Small Poultry Processing Plants and Services Directory
UMD-Extension: Maryland Niche Meats and Poultry Directory
Natural Maryland: Poultry Vendors Directory
Sustainable Agriculture Resource and Education Learning Center
Maryland Organic Free Range Chickens Directory
American Pastured Poultry Producers Association (APPPA) Member Directory
American Grassfed: Maryland Producers Directory
FarmPlate Beta: Producers Directory
DC Food: Maryland Beef and Poultry Directory
www.Yelp.com
Appendix B: Introduction (Chapter One) References


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8.1 Curriculum Vitae

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Education

Wesleyan University, Bachelors of Art. (English) 2002-2006

Johns Hopkins Bloomberg School of Public Health, Masters of Science in Public Health (Occupational and Environmental Health) 2010-2011

Johns Hopkins Bloomberg School of Public Health, PhD (Environmental Health Engineering) 2011-2015

Professional Experience

Research Assistant, Center for a Livable Future 2011-present

Graduate Research Assistant, USDA Office of Risk Assessment and Cost-Benefit Analysis 2013-2014

Teaching Assistant, JHSPH 2012-2013

Selected Publications


