ABSTRACT

Lehrke, Linda D.; M.S.; Department of Agribusiness and Applied Economics; College of Agriculture, Food Systems, and Natural Resources; North Dakota State University; November 2006. Determining and Evaluating Cost-Effective Intervention Food Safety Risk Reduction Strategies at Retail Meat Facilities. Major Professor: Dr. William E. Nganje.

In spite of the documented success of Pathogen Reduction and Hazard Analysis and Critical Control Points (PR/HACCP) at the processing level, farm-level and retail-level application is optional. Several factors impact the gap of food safety regulations from farm to fork. This thesis focuses on the retail level. At the retail level, pathogen survival and the associated ability to cause further disease to humans even after being subjected to certain processing and packaging conditions have varying implications on the probability of sickness or death. This issue also arises over the fact that, sometimes, appropriate handling and processing instructions are not properly followed by consumers.

The primary goals of the project are to develop an optimal food safety intervention strategy that incorporates risk, cost, and the value of pathogen reduction with alternative control mechanism. We wish to evaluate incentives for PR/HACCP-like planning and adherence to best management practices that promote safe food production. These incentives will be evaluated for the retail level. In addition, we will develop optimal intervention strategies for ready-to-eat meats and poultry products that incorporate risk assessment, cost of intervention, and the value of risk reduction of alternative strategies for the farm-to-table continuum.

The model adopted in this study is an expansion of the stochastic optimization model developed by Nganje, Kaitibie, and Sorin (2005) to include the optimal intervention strategy at the retail (consumer) level. These components are simulated with firm-level microbial data at the processing and retail level using stochastic optimizer software. Stochastic dominance was also used to compare across the optimal strategies and determine if there is one clear choice that is preferred. This allowed us incorporate risk preferences of firms. Scenario method was used to determine what factors would likely affect the adoption of PR/HACCP at the retail level. Finally this thesis provides firms and policymakers a direction for future options concerning risk mitigations strategies.

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I would like to dedicate this thesis to my sister, Julie Lehrke, for her support and also for being a friend and a role model to me. I also want to dedicate this thesis to my boyfriend, Brandon Burbidge, for always reminding me that "school comes first." Also, thanks to my friends and family for their general interest and support over the past 18 months.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1. INTRODUCTION

Background

Consumers make choices about food products based on several factors such as product price, quality, and safety. In an efficient market, choices would be made with full information about product attributes. The real-world market for food products is not necessarily efficient, and food safety problems complicate consumer decision making. Food safety is a credence attribute. This means consumers cannot tell with certainty the level of microbial pathogens that are present in meat and poultry products at the time of purchase or even thereafter. Producers and processors may have this information but find no incentive to share it with consumers because it is difficult to charge a premium for an unobservable increase in food safety (Buzby et al., 1998). Although Antle (1998) makes a case for symmetry between producers and consumers on the lack of information on product safety, there exists a breakdown in market structure due to unavailability of relevant information on food safety, and this implies a need for government intervention. Regulations designed to reduce the level of microbial pathogens, in general, may improve public welfare (Starbird, 2000).

In 1996, the Food Safety Inspection Service (FSIS) introduced new mandatory food safety regulations following repeated discoveries of E. *coli* and *Salmonella* in the U.S. food supply in the 1980s and early 1990s. The new regulations, called Pathogen Reduction/Hazard Analysis and Critical Control Points (PR/HACCP), mandated the establishment of critical control points (CCPs) in food production and processing operations and established testing routines for potentially hazardous food products to ensure the safety of meat and poultry products. By 2000, these regulations had been adopted by meat and poultry processors. Figure 1.1 from CDC FoodNet (Liang 2006) reveals that pathogen levels have decreased after the adoption of mandatory PR/HACCP in meat and poultry processing. This includes a 30% reduction in *Camplylobacter*, a 9% reduction in *Salmonella*, a 32% reduction in *Listeria*, and a 29% reduction in *E. coli* O157 (Liang 2006). However, Figure 1.1 also shows that there has been an increase of 41% in Vibro, a bacterial pathogen as well, most commonly caused by eating raw or improperly prepared seafood.

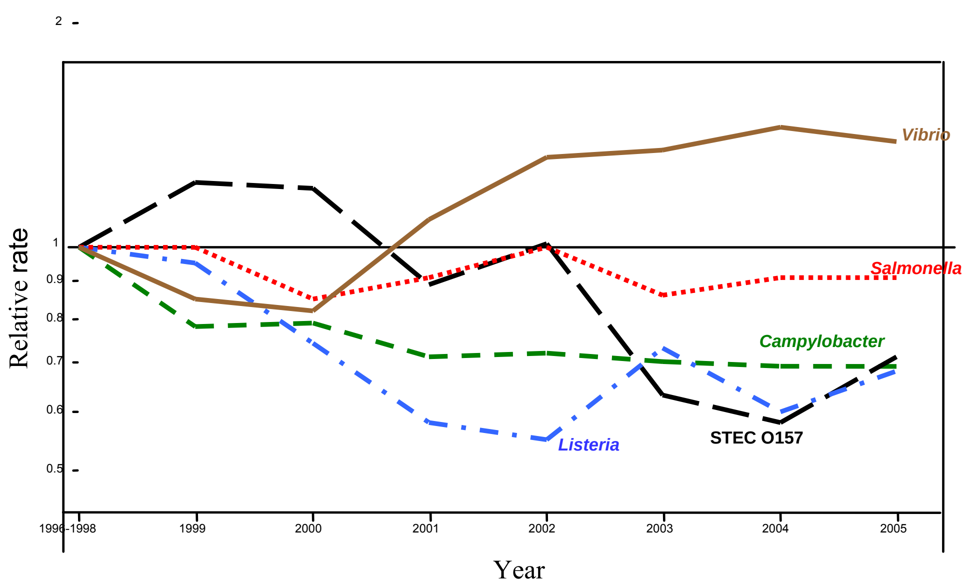


Figure 1.1. Trends: Relative Rates Compared with 1996–1998 Baseline Period of Laboratory-Diagnosed Cases of Infection with *Campylobacter*, STEC O157, *Listeria*, *Salmonella* and *Vibrio*, by Year.

While most bacterial pathogens have been decreasing since 1996, the prevalence of viral pathogens has been increasing. Figure 1.2 shows the role of viruses and other pathogens in foodborne illness outbreaks from 1990 to 2004 (Liang 2006). The level of foodborne illnesses caused by chemicals and parasites is low. The foodborne illnesses caused by bacteria have fluctuated greatly, but have gone down slightly during the past 14 years. Viruses have shown a major increase since 1990. Viruses have even surpassed bacteria in the number of outbreaks occurring in 2004. Studies suggest that the reduction of foodborne bacterial pathogens creates a less competitive environment for viral pathogens.

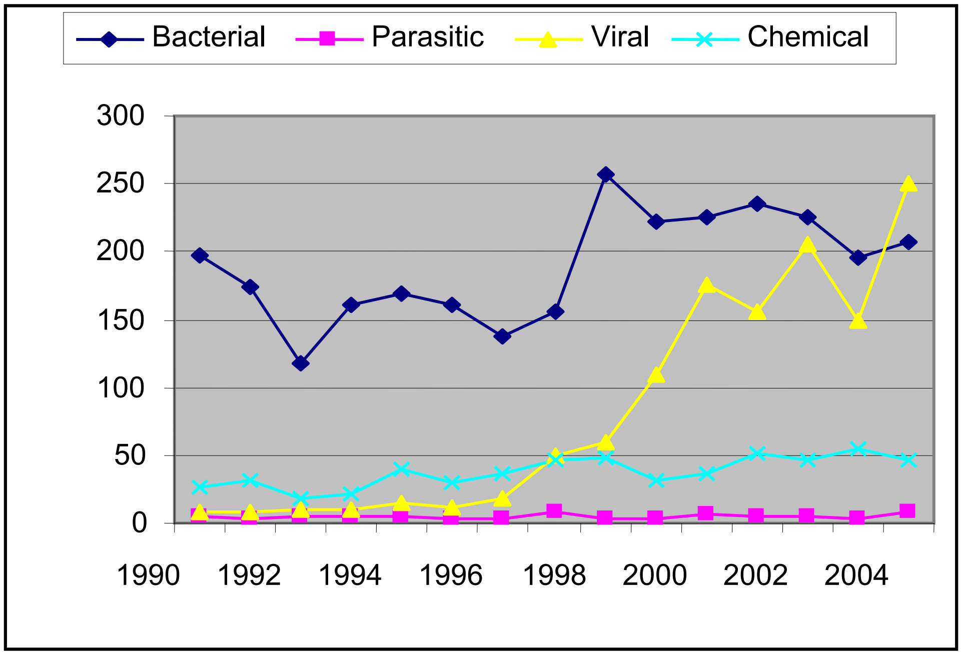


Figure 1.2. Role of Viruses in Outbreaks of Foodborne Illness, 1990-2004.

One critical observation is that a dichotomy exists between pathogen levels and increasing outbreaks from retail facilities (Liang 2006). Figure 1.3 shows the trend in multi-state outbreaks from 1990-2004 (Liang 2006). In the early 1990s, the number of outbreaks increased, and it peaked in 2000. After 2000, there was some reduction, but in 2003, there was a large increase in outbreaks.

Nationwide, the number of all foodborne illness outbreaks per year has increased. Figure 1.4 shows the foodborne illness surveillance from 1983 to 2004 (Liang 2006). In this figure, you can see that the general trend in outbreaks is increasing, even though the pathogen prevalence is lower.

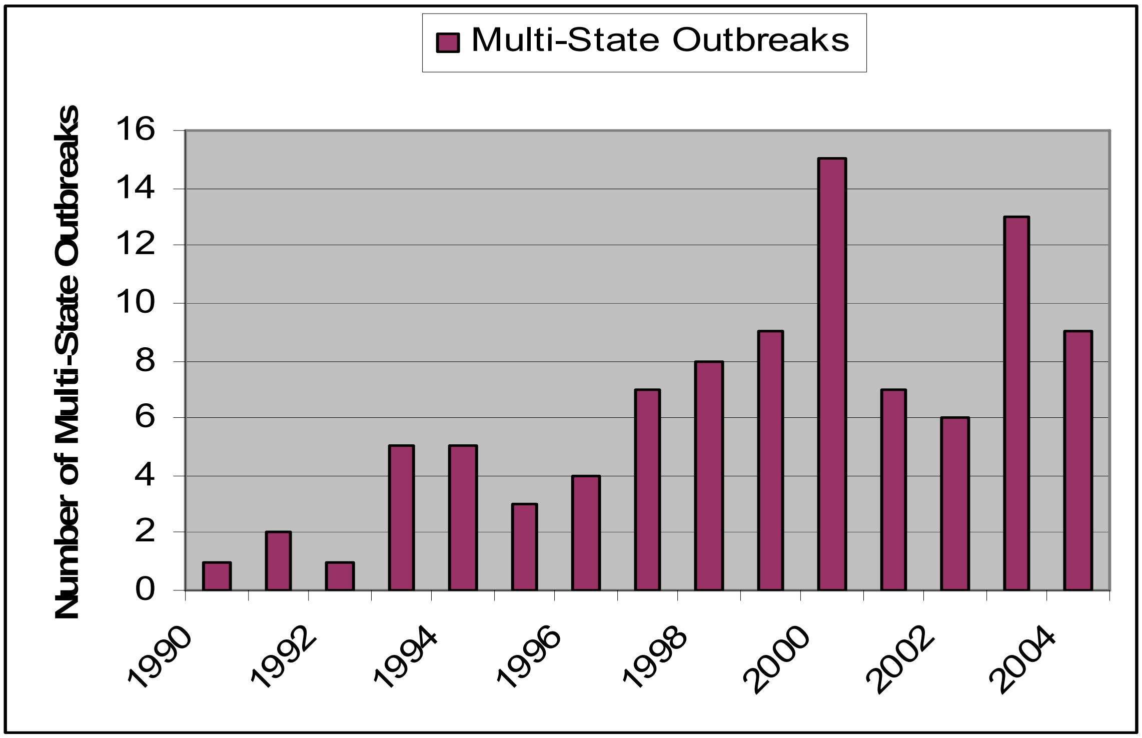


Figure 1.3. Trends: Number of Multi-State Outbreaks, 1990-2004.

In looking at *E. coli* O157:H7 outbreaks, Figure 1.5 shows the incidence of reported cases from 1982-2002 (Liang 2006). The trend is also increasing throughout the 1980s and 1990s with a peak in 2000. However, the number of reported cases in 2001 and 2002 is still quite large, larger than the numbers of cases reported prior to 1995.

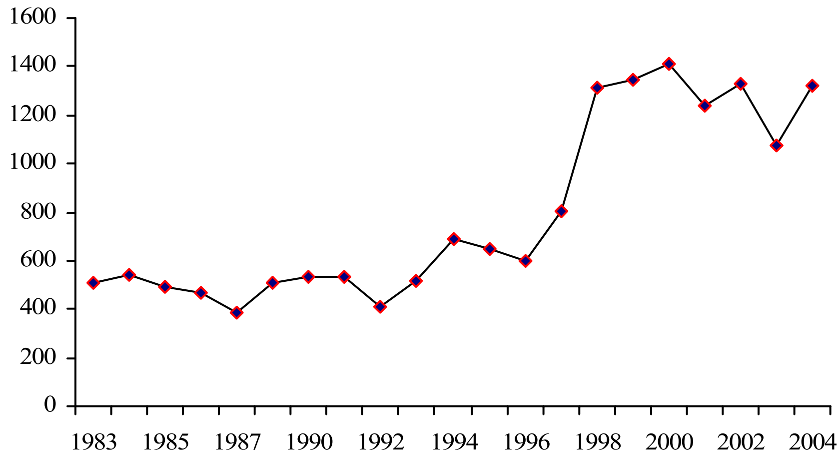


Figure 1.4. Trends: Foodborne Disease Outbreak Surveillance System.

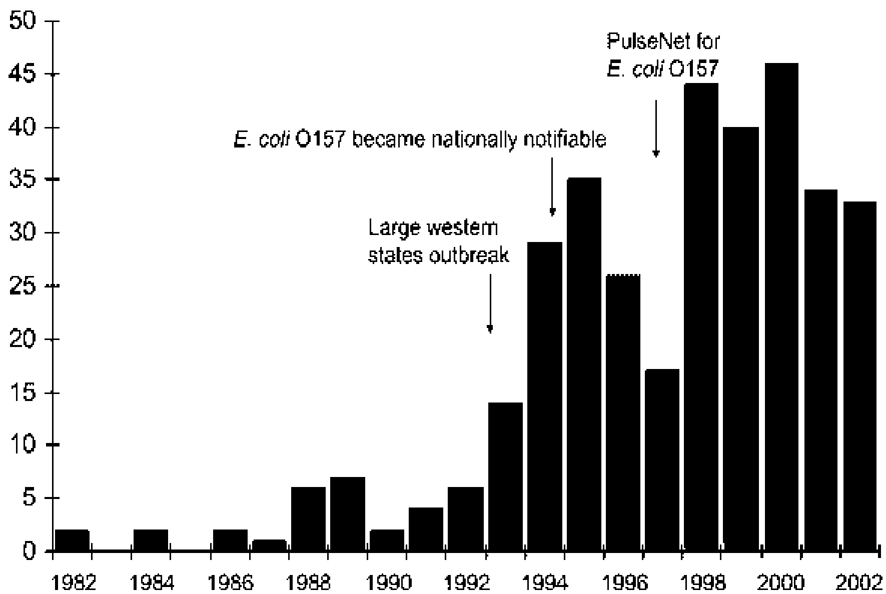


Figure 1.5. Trends: Reported Outbreaks of *E. coli* O157:H7 Infections in the United States, 1982-2002.

The dichotomy between pathogen prevalence and outbreaks suggests a need for policymakers to better understand incentives to assist other sectors along the supply chain to implement a safer food safety system and external penalties to motivate adoption of protocols of PR/HACCP. The effectiveness of food safety legislation based on performance standards depends on how inspection policies and economic penalties interact to influence processor behavior (Starbird 2000).

Problem Statement

In spite of the decreasing trends of some major pathogens after PR/HACCP at the processing level, farm and retail level application are optional. Several factors impact the gap of food safety regulations from farm to fork. First, separate agencies are responsible for food safety along the farm-to-fork continuum. For example, the FSIS is responsible at the processing and packaging level while FDA is responsible for food safety regulations at the retail level. Second, limitations on the link between pre- and post harvest pathogen loads reduce the effectiveness of food safety risk mitigation strategies like PR/HACCP. *Salmonella* and E. *coli* have been repeatedly isolated from production systems and are known to have a ubiquitous distribution. In addition, there is a distinction between the virulent and non-virulent strains of pathogens. Intervention strategies for combating virulent strains of pathogens vary from farm-to-fork. The implementation of PR/HACCP at the pre-harvest or retail levels in the United States is optional.

Even though HACCP is mandatory at the processing level, there are still significant levels of outbreaks occurring in the United States. The trend in foodborne illness outbreaks are upward even though pathogen prevalence has been decreasing since the PR/HACCP final rule in 1996. While some of these increases are due to viral pathogens, bacterial pathogens still create a significant amount of the foodborne illness cases each year. This could be because performance standards at the processing level need to be tightened; it could also signal a need for PR/HACCP at the retail level.

Currently, food service and retail facilities are implementing various forms of intervention, including voluntary PR/HACCP. Three strategies for pathogen reduction are currently being used at the retail level. These strategies involve different combinations of testing by the USDA and/or outside firms, maintaining hygiene standards with standard operating procedures (SOPs), and testing done by the retail firm itself. All firms are required to maintain SOP standards and to have random checks conducted periodically by the USDA. Others expand this requirement to include pathogen testing, which is conducted by a private firm (like Fresh Check) that the retail firm hires. A third strategy is voluntary RP/HACCP, where firms develop and maintain a HACCP plan. An important question is to understand which of these strategies is cost-effective in reducing pathogen at the retail level.

Objectives

The primary goals of the project are to evaluate the cost-effectiveness of intervention strategies for pathogen reduction at the retail level of the food supply chain for meat. The specific goals are as follows:

1. Provide a detailed review of alternative food safety risk mitigation strategies along the meat supply chain, including cost, risks, and benefits of the strategies.

2. Develop optimal intervention strategies for each risk mitigation strategy employed in retail facilities.

3. Use stochastic dominance methods to compare alternative cost-effective mitigation strategies.

4. Use scenario methods to evaluate driver and dependent variables that could facilitate PR/HACCP at retail facilities.

Once all of the objectives are completed, the expected outcome is that PR/HACCP will be the most cost-effective strategy at the retail level.

Stochastic optimization and stochastic dominance methods are used, which incorporate multiple risk factors, to evaluate cost-effective strategies at meat retail facilities. Retail data on pathogen prevalence for *E. coli, Salmonella*, and *Campylobacter* (collected by North Dakota State University microbiologists at North Dakota retail facilities) and the cost of intervention for three alternative strategies were evaluated for beef, chicken, turkey, and pork. The associated risks, costs, and benefits of alternative mitigation strategies are evaluated jointly in this model.

Thesis Outline

Chapter 2 provides the literature review evaluating food safety mitigation strategies, specifically with emphasis on HACCP implementation. Chapter 3 presents the theoretical framework of the study as well as data and the procedure for completing the study and data used to simulate variables in the model. In Chapter 4, Results of the study are discussed. Finally, Chapter 5 presents the conclusions and discusses the policy implications for firms and policymakers.

CHAPTER 2. REVIEW OF LITERATURE

Food Safety Intervention Strategies

There are more than 200 known diseases that are transmitted through food. The Centers for Disease Control and Prevention (CDC) estimates that between 6 million and 81 million illnesses each year are caused by foodborne diseases. Foodborne illness can be fatal and they are estimated to cause up to 36,000 hospitalizations and 9,000 deaths per year. The economic cost of these sicknesses and deaths are estimated in billions of dollars (CDC, 2005).

Costs and Benefits of Food Safety Regulation

The demand for improved food safety has induced changes in methods used in meat processing for pathogen control. The adoption of new technologies allows the processing firm to achieve a safer food product through reduced pathogen levels. The challenge becomes finding a set of interventions which is cost-effective for achieving pathogen control. In a paper by Jensen, Unnevehr, and Gomez (1998), this issue is addressed. The paper specifically addresses the structure of costs incurred by the firm in applying interventions to control food safety in meat processing, and new data on the cost and effectiveness of selected food safety interventions in beef and pork processing.

An econometric analysis of the costs for the major stages of the production process was done. Each process contains a critical control point. The major stages are incoming animals, pre-evisceration, post-evisceration, and packing and fabrication. The stages were evaluated using several different technologies of control in terms of their effect on reducing pathogens. The cost data were obtained from input suppliers of the food safety technology. Depreciation and operating costs were constructed for the equipment.

Meat pathogen reduction of the different technologies was collected. Some of the highest levels of pathogen reduction were seen by using a combination of the technologies, such as, a hot water wash, a steam vacuum, steam pasteurization, a lactic acid rinse and trimming. Combinations of two or more stages resulted in the highest pathogen reduction. On the cost side, sanitizing sprays were the highest per carcass at $0.41, water rinses were $0.37, steam vacuum was $0.34, steam pasteurization was $0.27 and trimming was $0.17. The study did not include the costs of monitoring and testing. Including monitoring and testing cost will increase the cost. The most cost-effective technologies were: steam pasteurization, trimming, a combination of trimming and a water rinse, and a combination of trimming, a water rinse, a lactic acid rinse, and steam pasteurization. Most of the firms were currently using the most cost-effective combinations already.

The economic impacts of food safety regulations (e.g. HACCP) have been evaluated at the societal and the firm levels. The method used by the Economic Research Service (ERS) for evaluating benefits at the societal level is called a Social Accounting Matrix (SAM). A SAM is a snapshot view of the circular flow of accounts in an economy. It represents national income and product accounts and Input-Output production accounts as debits and credits in balance sheets of activities and institutions.

The Economic Research Service of the USDA (Golan et. al., 2000) did an economic study to determine the impact of the HACCP program for the meat and poultry industry. The framework used to evaluate HACCP was a SAM. In the HACCP SAM, the accounts focus on the primary activities and institutions affected by foodborne illness or by HACCP programs. The HACCP SAM deals with the macroeconomic perspective of the costs and benefits of HACCP.

The results of the study show that all consumers would have a total benefit of $8.24 billion. The majority of that benefit was captured by families with children who were above poverty, collecting about $4.90 billion, or 50% of the total benefit. This makes sense because children are at a higher risk of falling ill from foodborne pathogens. The estimate of additional firm-level costs was $1.1 billion. This estimate took labor, transportation, chemical, medical service, and general manufacturing costs into account. It ignored any productivity losses because of HACCP implementation and also the variable costs of production. Since the ERS study, many other economists and food safety experts have analyzed HACCP at the firm level.

There are two opposing concepts about the costs and benefits of food safety regulations like HAACP. Assessments done by the Regulatory Impact Assessment (RIA) and the FSIS found that the benefits outweigh the costs by such a wide margin that HACCP regulations could be viewed as providing a virtual "free lunch." This implies that the meat industry could provide a substantial increase in the safety of its products, perhaps even completely eliminating all risk of foodborne pathogens at a cost estimated by the FSIS to be less than .01 cent per pound of product (Antle 2000). Antle also states that the RIA and the FSIS made various assumptions to estimate the costs of HACCP regulation. The FSIS assessment was based on an accounting of the estimated costs of quality-control activities for typical small, medium, and large plants. These costs included the development of the HACCP plan, the costs of process modifications believed necessary to implement the HACCP plan, and record-keeping and product-testing costs. However, the FSIS assessment did not account for any increases in plant operating costs or productivity losses caused by the implementation of the regulations. This could skew the FSIS results because variable costs of production represent over 90% of total costs of production for the typical meat and poultry processing plant in the industry (Antle 2000).

There are several interesting observations about the cost of mandatory food safety regulation. For example, why are there still significant outbreaks of foodborne disease in the United States in spite of a mandatory HACCP regulation? Are the regulations too expensive and producers cannot fully comply?

An ERS study, done by Crutchfield and Allshouse (1998), states that measuring the costs of food safety accurately can strongly influence policy and programs. They use a cost-benefit analysis to look at the HACCP program. Price, convenience, appearance, nutritional content, and other factors influence choice in the market place. Because food safety is not discernible to consumers when they purchase products, they do not have perfect information about the product. Because of this, there are few incentives for producers to provide levels of safety beyond what is mandated by the federal government, even though the cost of having products linked to outbreaks (reputation and sales) is high. This makes it impossible to achieve an optimal level of food safety in a non-regulated market.

The paper by Crutchfield and Allshouse (1998) used a "Cost of Illness" study. The "Cost of Illness" (COI) approach is a way to measure the sum of the expenses incurred when an individual falls ill due to foodborne illness. It takes into account losses in productivity and medical expenses in cases of illness and death. This method is easy to use and understand. One disadvantage of a COI study is that it does not take into account the value of being healthy or the loss of free time of individuals. It also places lower values on the elderly because they have low future earning or no lost productivity if they are retired.

Several scenarios were used to estimate the benefits. One set showed smaller benefit estimates, a second scenario yielded mid-range estimates, and a third was the estimate of the greatest possible benefits. The results show that the benefits of HACCP outweigh the costs in each scenario. Thus HACCP will contribute to the UNITED STATES economy and welfare from reduction in medical costs and productivity losses.

Foodborne illness causes significant social and economic burden. Regulatory authority over food safety is divided among several agencies. However, food safety is everybody's responsibility, including the consumers. There are two sources of uncertainty which affect the estimates of the cost of foodborne illness: 1) uncertainty of the number of cases of foodborne illnesses per year (the nature, severity, and underlying causes), and 2) imperfect knowledge about the sources of risk along the food chain. The goal is to develop more accurate and concise estimates of social costs of foodborne illness.

Over the past 10 years, *E. coli* O157:H7 has cost the beef industry as much as $2.7 billion (Kay 2003). The estimated costs of a food recall are high and have a significant impact on firms' performance. Firms suffer losses not only from liabilities, but also from increased operating costs, recall costs, and loss of market share. In fact, the greatest food safety losses to the beef industry over the past ten years have been due to the impact on demand for beef.

The costs of implementing a food safety plan, such as HACCP, vary from firm to firm. The main costs to plants associated with HACCP regulation are implementation costs (including plan development, training, and remodeling) and operating expenses (quality costs, and testing and sampling costs). In a study done by Nganje, Mazzocco, and McKeith (1999), HACCP costs were evaluated with the major concern of small firms in mind. The purpose of this study was to do a firm-level analysis of HACCP costs and to determine if these new costs would affect output price and eventually profitability of a firm.

Nganje, Mazzocco, and McKeith put a survey together to obtain some much needed firm-level data on prices and costs before and after HACCP implementation. The questionnaire had three sections: one on the firm's characteristics, one on total production and expenses, and one on HACCP performance and expenses. Once the surveys were returned, they were able to use data from 34 of the responses that came from small processing firms. The range of HACCP expenses from these firms was between 0.04 and 43.51 cents per pound, which is relatively larger than the USDA's previous estimates of 0.24 cents per pound.

A translog profit function was used in the Nganje, Mazzocco, and McKeith paper (1999). This is because it analyzes profitability, output price and technology jointly. It also incorporates a firm's desire to maximize profits. Four different profit share functions were used for profits after HACCP implementation to include labor, carcass, materials, and HACCP costs. Three were used for profits prior to implementation to include labor, carcass, and material costs. The results of the study show that profits prior to HACCP were $259,839; $303,098; and $230,536. These were averages of all 34 firms. The profits after HACCP implementation were $413,537.; $330,355; $327,825; and $358,704. These show that the net profits after HACCP implementation were significantly greater than before HACCP. This means that mandatory food safety regulations, such as HACCP, can significantly increase the efficiency of firms, even small firms.

Although the costs of food safety outbreaks and mitigation expenses are well understood (FSIS, USDA, 1996, Buzby et. al., 1998, Golan et. al., 2000, Kay, 2003) methods to quantify the benefits provide conflicting results because most of the benefits are intangible, and often these may vary depending on whether the emphasis is on benefits to a society as a whole or benefits at the firm level. Benefits to society as a whole have been estimated using cost-of-illness methods (e.g. in the HACCP SAM) or the value of statistical life.

Salin (2000) used a real options model to quantify food safety risks at the firm-level. This study begins with a firm needing to satisfy HACCP requirements by investing in new equipment. The uncertainty about the returns from this investment comes from market risk, and food safety risk. The returns to the investment are estimated by incorporating risk of food safety events (recalls) occurring. In the study, price and production were allowed to vary subject to discrete "jumps" in returns. These "jumps" captured the probability of a food safety event.

The findings show that the frequency of a "jump" has a larger effect on the option value than the size of the "jump". When the frequency of the jump was 0.9 and the project value was about 1.45, the option value was 0.7. If the jump were 0.1 at a 1.45 project value, the option value was 0.4. Conversely, if the project value were reduced to 0.65 and the jump parameter were 0.9, the option would have no value. Holding the project value constant at 0.65 and decreasing the jump parameter to 0.1, the option value increases to about 0.4. This means that decrease in the probability of occurrence of a food safety event can either raise or reduce the option value. This is contrary to the risk-return theory of higher risk provides higher option value and vice versa. This implies that any risk-reducing effects of HACCP might not increase the incentives in risk reducing measures by the food industry. However, the unexpected results occur when the probability of an event is low and the project value is small. Thus risk-reduction through HACCP would provide greater incentive for larger firms.

Intervention Strategy for Slaughtering, Packing, and Processing Facilities

Since January 2000, all federal and state inspected meat packaging and processing firms are mandated to implement PR/HACCP practices. PR/HACCP mandates that the processing firms establish critical control points (CCPs) where the probability of pathogen contamination is high and monitor the level of pathogen presence at these stages. The monitoring is done through pathogen testing and record keeping. This testing aids in pathogen reduction and helps ensure that safer products are being produced and delivered to retailers. Even though PR/HACCP is progressing smoothly, there are still challenges.

One challenge is that FSIS inspectors are responsible for carrying out the verification process. They must review all the practices of the firm and assess the record keeping. This can be difficult if the firm appears to be following legislation, but is really falsifying records. The FSIS relies heavily on whistleblowers, or employees or persons who assist the USDA achieve compliance with the regulations. The FSIS must ensure that the identity of the whistleblower is protected to continue this relationship.

Small processing firms present another challenge. This is because of the lack of familiarity with PR/HACCP that previously existed in larger firms. The FSIS provided assistance activities and developed generic PR/HACCP plans that facilitated easier implementation. The generic plans were not a blueprint, but rather an illustration to help remove some of the guess work involved in developing PR/HACCP plans. These generic plans also helped reduce costs to the “small” and “very small” firms. The FSIS also provided guides and various other materials to assist these establishments.

Some of the previous challenges faced by the processing sector will most likely be faced by the retail sector if PR/HACCP is proven to be an effective means for pathogen reduction at the retail level.

Costs and Incentives of Alternative Intervention Strategies at the Production and Processing Level

Nganje, Siaplay, and Kaitibie (2005) used Value at Risk (VaR) to estimate the downside food safety risk for a turkey processing plant. VaR is a method that projects the downside risk of an investment given a particular confidence interval. Thus it shows the firm the maximum amount it might lose by investing and what percentage of the time that might occur. The purpose of the study was to determine whether a turkey processing firm's losses due to food recalls prior to and after HACCP were significantly different. The VaR was estimated for three alternative scenarios: prior to HACCP implementation, during HACCP implementation, and after HACCP implementation. Historic simulation was used to estimate the VaR on a one-month time horizon for each of the three scenarios. Historical data on turkey recall, turkey prices, microbial levels, and turkey processing costs were used to calculate the VaR in each scenario. The net economic benefit of HAACP was added or subtracted from the turkey processing margin to adjust for increases or decreases in profit for the two scenarios involving HACCP. The results of the study show that VaR is lowest after HACCP implementation. VaR prior to HACCP implementation is -0.06905 dollars per pound of turkey per month. The VaR after HACCP implementation is -0.04936 dollars per pound of turkey per month. This is a reduction in VaR of 0.01969 dollars per pound of turkey per month.

Nganje, Kaitibie, and Sorin (2005) used the Taguchi loss function to estimate the cost of quality loss in turkey processing. The objective of the study was to determine if a generic HACCP plan is economically effective for a turkey processor to provide safe food products, and if not, which critical control points (CCPs) need to be added to improve the plan. The net benefit of HACCP was measured as a function of quality loss, testing and sampling costs, and the value of risk reduction. The study showed that there was a need for the turkey processing plant to establish more CCPs than those included in the generic plan (two CCPs in this case). They showed that the *Salmonella* performance standard could be reduced to 15%, but reduction of performance standard below 10% would result in disproportional cost increases for processing firms.

Intervention Strategies at Retail Facilities

Three strategies for pathogen reduction are currently being used at the retail level. These strategies involve different combinations of testing by the USDA and/or outside firms, standard operating procedures (SOPs) done internally, and testing done by the retail firm itself. The proceeding section will describe the different strategy combinations.

Strategy One

The first strategy that can be adopted by a retail firm is to do SOPs internally and to have random checks by the USDA. These two procedures must always be done at the retail level. Every strategy will include random testing by the USDA and SOPs to be performed internally. The random testing by the USDA involves swab tests. Swab tests provide information on pathogen counts. The USDA also checks to be sure that SOPs are being done by the employees at the firm.

The SOPs at the retail meat level involve taking temperature logs, grinding logs, sanitizing logs and checks, and cleaning check lists. The purpose of the temperature log is to ensure that all freezers and coolers remain at the proper temperature. If at anytime the temperature increases above what is recommended, the product in that particular freezer or cooler can be discarded or salvaged depending on the time period between the temperature checks. These checks are typically done every four hours, this way most products can be salvaged if there is a problem with the refrigeration system. The grinding logs are used to keep track of how much meat has been ground and when it is ground. The sanitizing logs show equipment and tools have been sanitized properly. The potency of the sanitizer is also sampled and must meet the correct standards for eliminating pathogens (this is usually measured in ppm). Cleaning logs demonstrate that the establishment is kept neat. When work areas are clean this directly reduces the risk of physical and chemical contamination and indirectly reduces the risk of microbial contamination.

Strategy Two

The second strategy is to have the USDA test randomly and perform the SOPs internally as described above, but in addition to those mandatory interventions, the retail firm will hire an outside firm to do random testing and checks. These firms are private companies that do similar checks as compared to the USDA. They also use swab testing and show up at the retail facilities at random.

Strategy Three

The third and final strategy that is currently adopted by retail firms is to still have random USDA testing and SOPs performed internally, but in this instance, the retail firm will also do pathogen testing. This strategy is less common. When strategy three is implemented, swab tests are used to collect microbial data and these swabs are done at random.

Challenges in quantifying the cost and risk reduction effects of alternative mitigation strategies exist, and will be addressed in the methodology section.

CHAPTER 3. METHODOLOGY, PROCEDURES, AND DATA

This study uses three different frameworks. Stochastic simulation is used to maximize utility of a firm. The utility is measured under different risk attitudes to ensure robust results. Utility is maximized subject to testing and sampling constraints. The solution where utility is maximized signifies the most cost-effective intervention strategy for that specific tolerance level, pathogen type and meat type. Once the optimal intervention strategies are determined, stochastic dominance is used to rank the optimal strategies. This ranking will allow for a clearer idea of the best single strategy, but also the tolerance level that is most appropriate to use. Factors other than cost-effectiveness can influence food safety policy. After ranking the strategies, scenario methods will be used to determine what factors will be key factors in causing the adoption of mandatory PR/HACCP at the retail level. Understanding what factors will affect the adoption of PR/HACCP at the retail level will help draw better conclusions about the effect future food safety policies might have for these facilities.

Decision Making Under Risk and Uncertainty

A decision problem exists when a firm has alternative choices. Uncertain consequences about the choice make the problem risky. Decision theory focuses on making the preferred choice (Robison and Barry 1987). A firm will want to determine the best strategy given a probability of certain risk factors.

The expected utility maximization framework has been used extensively to model investment decisions under risk and uncertainty. Expected utility theory states that, when faced with uncertainty, people behave or should behave as if they were maximizing the expectation of some utility function evaluated over the possible outcomes. If a firm has an expected utility function that exhibits diminishing marginal utility of wealth, the firm is risk averse. Diminishing marginal utility of wealth suggests that each additional dollar obtained provides less utility than the dollar before it. This means that as a firm's wealth increases, their risk aversion decreases. Risk-averse firms will avoid taking risks by paying a risk premium.

There are limitations to the expected utility framework. The Allais Paradox (Frechette and Tuthill, 2000) shows that the addition of equivalent consequences can lead people to make different choices. This means that given two options, the option with the highest expected utility might not always be chosen, due to independent event influences. Limitations can be overcome by evaluating the robustness of the model. The framework can also be approximated by using a risk-return model that incorporates risk attitudes or preferences. The use of a weighted expected utility model can be used to account for deviations from the expected utility outcomes that occur for small-probability events, as suggested by the Allais Paradox.

In this study, firms are assumed to maximize the expected utility of net benefits. Net benefits are comprised of total revenue minus total cost, which is a function of the decision to test for pathogens and sampling intensity. We represent firm risk preferences using an expo-power utility function (Saha, 1993). This function has the flexibility to exhibit different risk-preference structures.

The expected utility maximization model will be subject to an economic constraint. Economic theory asserts that a perfectly competitive firm maximizes profit (Nicholson, 2002). If a firm wants to increase profit it must either increase total revenue or decrease total costs or both. Another assumption of perfectly competitive firms is that they are price takers (Nicholson, 2002). This means that the only control the firm exudes over profit is the ability to decrease total costs or change output.

The costs of food safety for existing HACCP plans at the firm-level have been evaluated by Antle (2000) Starbird (2000), Nganje, Kaitibie, Sorin (2005). These analyses did not extend their models into the retail-level, or do not include the probability of pathogen survival, especially within the framework of consumer susceptibility.

A Framework to Evaluate Cost-Effectiveness for Alternative Intervention Strategies

The framework adopted in this study is a stochastic optimization model developed by Nganje, Kaitibie, and Sorin (2005). Their emphasis was to evaluate the effectiveness of generic and augmented PR/HACCP models for turkey processing. This framework is used to evaluate strategy at the retail level for alternative products and pathogens (Figure 3.1). The associated risks, costs and benefits of alternative mitigation strategies are evaluated jointly in this model.

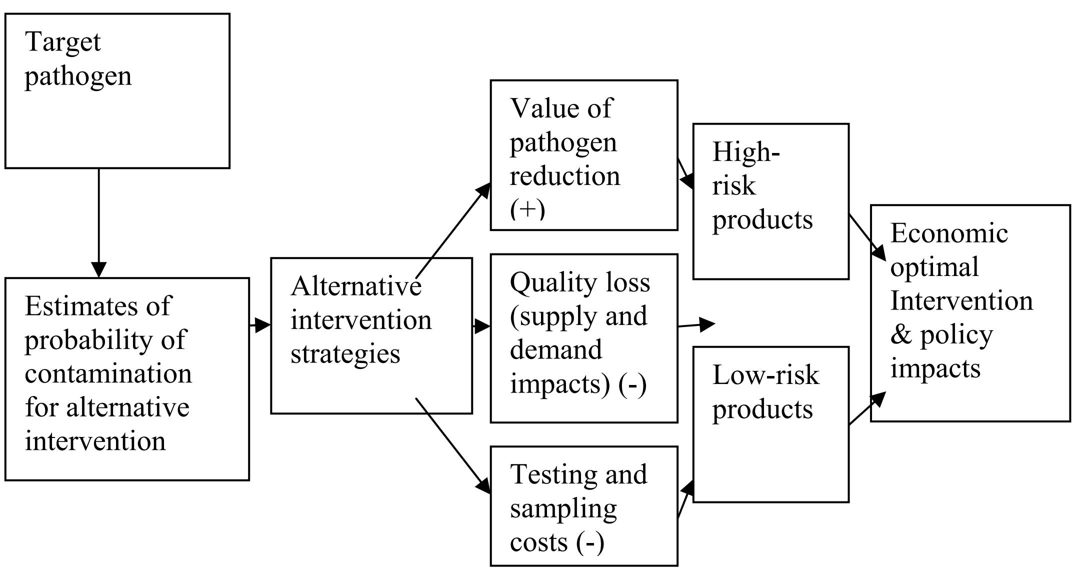


Figure 3.1. Schematic Representation of Processes in Firm-Level HACCP Assessment and Augmentation with Extension into Retail Level.

These components are simulated with firm-level microbial data at the processing and retail level using stochastic optimizer software, with the objective function being a net revenue function and the choice variables being testing intensity and sampling decision. Extensions of the original model developed by Nganje, Sorin, and Kaitibie (2005) are made on the probability of contamination using survival analysis at the retail level. This framework includes three major components: pathogen prevalence, effectiveness of intervention strategy to reduce food safety issues, and the cost of intervention.

This study will evaluate three different strategies that are used by retail firms. The first strategy is the use of standard operating procedures and mandatory random inspection and testing by the USDA. The second strategy includes the first strategy but also includes the firm hiring a private agency to do pathogen testing and random checks. The third strategy includes the first strategy as well, but instead of hiring a private firm, the retail firm practices voluntary HACCP.

Probability of Pathogen Contamination

Generic and augmented HACCP systems have critical control points (CCPs) and critical limits. In reality, contamination does not necessarily occur to every product due to the effectiveness of PR/HACCP regulation and other food-safety measures. Before quality loss can be calculated, the probability of contamination, given a critical limit or tolerance level for each pathogen, was calculated to reflect the risk assessment objectives and the actual risk of contamination.

The marginal probability of contamination was estimated for each meat product by using a Risk Extreme Value (RiskExtValue) distribution and stochastic simulation. Pathogen levels at the final stage (on the shelf) are set equal to a function of the pathogen levels of each meat product times a survival function. When the pathogen level of the final product is less than the performance standard no violations occur and conversely when it is greater than the performance standard a violation has occurred. The marginal probabilities will be simulated for each meat product and pathogen type.

On the consumer side, pathogen survival and the associated ability to cause further disease to humans even after being subjected to certain processing and packaging conditions has varying implications on the probability of sickness or death. This issue also arises over the fact that sometimes appropriate handling and processing instructions are not properly followed by consumers. Survival analysis is a tool used to measure the length of time or duration of an event. In food safety, the length of time a pathogen survives or the length of time until a pathogen dies under certain conditions is of interest to this study. For example, if a certain bacteria can only survive for three seconds when exposed to temperatures at or above 180°F, we would say none of the particular bacteria survive over the interval of three seconds when the temperature is 180°F. Conversely, if the temperature is not over 180°F, bacteria will survive and multiply. This analysis is important to evaluate the probability of *Salmonella* occurrence at the processing and retail combined. Therefore this study additionally evaluates the probability of pathogen survival parameters using survival analysis, especially within the framework of consumer susceptibility demographics.

To extend this model into the retail level, survival analysis was used. In food safety, the length of time a pathogen survives or the length of time until a pathogen dies under certain conditions is central to determine final outcomes of alternative strategies. At the retail level, a survival analysis will be performed to identify pathogen survival parameters. Survival analysis characterized exposure and infectious doses of pathogens. Actual contamination data for ready-to-eat meats were used to estimate the probability of pathogen survival.

Value of Risk Reduction

The value of risk reduction could be greater than the total revenue because recall costs include total value of production, loss in market share value, and liability payments. The value of risk reduction is the additional benefit accruing to a firm which tests for a pathogen and implements specific intervention strategy.

The measure of risk reduction compensates the processor when the processor tests for pathogens at the CCPs and implements control measures if the tolerance level is violated. It is a measure of the benefit derived from not shutting down due to an outbreak. Hence the value of risk reduction is a function of the testing decision and the sampling intensity and it estimates the portion of total revenue which is retained at each CCP when an outbreak is prevented.

Cost of Intervention

The framework includes two main costs: quality loss and testing and sampling costs. Quality loss costs cover expenditures associated with ensuring that products conform to specifications. The conformance costs include costs of prevention and appraisal, while the nonconformance costs include the costs of internal and external failure. Internal failure occurs when *Salmonella* levels (the only performance standard pathogen with HACCP) are higher than the performance standard (e.g. 49% for ground turkey, 0% of ready-to-eat meats). The quality loss is measured with the Taguchi loss function (Taguchi, 1986). The loss function is a financial measure of user dissatisfaction with a product's performance as it deviates from a target safety value. The costs increase for testing and sampling as the sampling intensity increases.

When pathogen testing is done, certain costs are incurred. The main costs come from the cost of the test itself. Other costs, such as labor and the cost of utilities also accumulate. These are the direct costs of intervention. The costs that occur indirectly happen when a lot tests positive and must be rejected. Thus, the firm has purchased the product and then finds it to be contaminated and must discard that product.

Determining Pathogen Prevalence at the Retail Level

Risk at the Retail Level

Several factors contribute to the amount of risk incurred by the retail meat industry. These factors can be separated into three categories: 1) pathogen presence in meat products, 2) pathogen survival, and 3) recall possibilities. Recall possibilities include the financial or economic losses that occur if a recall is made and also the decrease in consumer confidence that is lost during and after a recall. The following sections will describe each type of risk and its implications in detail.

Pathogen Presence

While a meat product may have passed the HACCP standards at the processing level of the farm-to-fork continuum, there is still a probability that pathogen levels are present in the product. This is not a problem if the product is properly handled at the retail level and properly handled and cooked by the consumer. However, this could still pose a threat to the consumer especially if the consumer is at a higher risk for foodborne illness.

Pathogen Survival

Pathogen survival is a risk at the retail level for three reasons. The first reason is meat being shipped from a processing plant to a retail store can contain pathogens, while the level of pathogens may be so low that it is not detected by a microbial test, the pathogens could still survive and grow if the product is exposed to the appropriate environment. The second reason is that there is the potential for the same survival and growth once the meat product has been sold to the consumer if the consumer does not handle and cook the product properly. The retail meat firm only has control over pathogen growth while the product is in its care. Thus, the lower the probability that pathogens will survive in a meat product lower the risk incurred by the retail firm. The third reason pathogen survival and growth occurs is because of human error. This can come in the form of improperly trained employees or improper use of equipment.

Potential for a Recall

The two main parts of recall risk are financial loss or economic loss and loss of consumer confidence. The financial losses occur because recalls involve consumers returning the affected products for a refund (which could be as much as an entire day's worth of revenue). Another reason for financial loss or economic loss is internal quality loss, which happens when products deviate from performance standards. Components of quality loss are decreasing market prices, recall costs, and decreasing demand.

Decreasing demand also falls under the category of loss in consumer confidence. This loss can be the greatest recall cost. Empirical evidence from Kay (2003) showed that decreasing demand represents about 60% of the total loss incurred by a firm.

The Stochastic Optimization Model

As in the study done by Nganje, Kaitibie, and Sorin (2005), a stochastic simulation model will be used to determine the optimal intervention strategy for *Salmonella* testing. Expected utility will be maximized to determine which testing strategy is optimal for a processing firm.

The utility function being maximized is an expo-power utility function (Saha, 1993). It is the expected utility of the net benefit function. The net benefit is the value gained from testing products minus the cost incurred from testing the products. Variables of pathogen contamination, retail and wholesale meat price, product loss, product sales, and testing costs were made random and simulated in Risk Optimizer. Table 3.1 shows the distribution for each stochastic variable. Retail price and wholesale price reflect the monthly prices since 1970 and were fitted to a distribution. Each meat type was simulated separately.

Comparing Alternative Mitigation Strategies Using Stochastic Dominance

The stochastic optimization is used to determine the optimal intervention for each strategy. To effectively compare across the optimal strategies, stochastic dominance was used.

Stochastic dominance is a method that allows decision makers to assign rankings on alternative strategies while maximizing utility subject to some kind of risk preference. It incorporates the firm's preference for alternative strategies by using risk aversion coefficients. There are several different types of stochastic dominance. One type is called first-degree stochastic dominance. This means that, if one choice (A) is superior to another choice (B) over an entire range of values, it exhibits first-degree stochastic dominance.

Thus, the first derivative of function A is less than the first derivative of function B.

Table 3.1. Distribution of Random Variables.

Variable	**Distribution**	**Values**
Testing costs		
E. coli	RiskTriang	($100,$150,$200)
Campylobacter and *Salmonella*	Normal	Mean = $12, Standard Deviation = $2
Labor costs	Normal	Mean = $14, Standard Deviation = $6
Utilities cost	Fixed	$36
Retail Meat Price ($/lb)	Normal RiskTriang RiskWeibull RiskWeibull	Beef (2.46, 0.78) Chicken (0.84, 1.53, 1.82) Pork (0.054, 2.94, RiskShift(-0.82)) Turkey (0.054, 2.94, RiskShift(-0.82)) All were truncated at 0
Wholesale Meat Price ($/lb)	RiskWeibull RiskLogistic RiskLogistic RiskLogistic	Beef (0.04, 1.60, RiskShift(0.11)) Chicken (0.39, 0.22, 0.057) Pork (1.08, 0.095) Turkey (1.08, 0.095) All were truncated at 0
Product loss per month	Normal	Mean = 3880 lbs, Standard Deviation = 5354 lbs, truncated at 0
Product sold per month	RiskTriang	($75000, $98125, $156250)
Probability of Pathogen Contamination		
Campylobacter	RiskExtValue	Beef (0.0047414, 0.067669) Chicken (0.09914, 0.28768) Pork (0.0020025, 0.044248) Turkey (0.01403, 0.11492)
E. coli	RiskExtValue	Beef (0.42807, 0.47414) Chicken (0.43495, 0.47505) Pork (0.45307, 0.477) Turkey (0.48182, 0.47878)
Salmonella	RiskExtValue	Chicken (0.001687, 0.04065) Turkey (0.011295, 0.10344)

Another type, second-degree stochastic dominance, uses the second derivative of a function to determine the ranking. If function A has a second derivative that is greater than function B, then function A dominates function B. Third-degree stochastic dominance looks at the third derivative. If the third derivative of function A is less than function B, then function A dominates function B.

In this study, first-degree stochastic dominance was used. A lower risk aversion coefficient (RAC) of 0.000001 and an upper RAC of 0.1 were used to depict risk neutral and strong risk aversion. This helps capture a wide range of risk preferences.

SIMETAR software was used to calculate rankings using stochastic dominance for the lower and upper range of risk aversion coefficients.

Using Scenario Methods to Determine Factors that Facilitate PR/HACCP at Retail

When the appropriate rankings of the strategies are found, it will either validate or discredit the hypothesis of PR/HACCP being the most cost-effective mitigation strategy at the retail level. Then, scenario methods can be used to determine what factors or variables are likely to affect adoption of PR/HACCP at the retail level.

Scenario analysis is a type of analysis used to determine what factors or variables would be instrumental in generating a particular outcome. Instead of forecasting what a particular outcome will be scenario analysis allows you to envision the desired outcome and then determine what factors will lead to that outcome.

Micmac method is used to help determine what variables will have strong influence and strong dependence on the perceived outcome. Variables with strong influence are also called determinant variables. A determinant or influence variable with a high significance can have a large affect on the outcome, without being dependent on other factors to reach that specific outcome. A dependent variable can affect the outcome, but they are very sensitive to the evolution of the influence variables. So rather than influencing the outcome, they depend on how the influence variables react to the environment before they become of importance to the outcome (Godet, 1993).

Variables chosen can fall into three categories. Internal variables are variables inside the firm that can affect the outcome, such as costs. External variables are variables outside the industry that impact the outcome, such as, government policy and taxes. Competitive environment variables are variables in the industry that contributes to the outcome, such as demand and supply of products or price. Each of these variables is assigned a weight that corresponds to each of the other variables. The weights can range from 0 to 3. A weight of 0 means that the variable has no impact on the corresponding variable and 3 means it has a great impact on what happens to the corresponding variable. The weights of the variables are put into a matrix and the matrix is multiplied until it is stable. Micmac then generates a report on the strong driver and dependent variables.

In this study, we identified thirteen variables from the internal, external, and competitive environment that could be instrumental in the implementation of PR/HACCP at the retail level. There were five internal variables, four competitive variables and four external variables. The internal variables included cost of restructuring the operation, the cost of microbial testing, labor costs to train employees on PR/HACCP, the firm's probability of having a foodborne illness outbreak, and the benefits accruing to the firm from PR/HACCP implementation. The competitive variables included the number of firms adopting PR/HACCP plans, the price of meat products, the demand for meat products, and the supply of meat products. The external variables included the number of foodborne illness outbreaks occurring nationally, the public demand for food policy changes, consumer education about safe food practices, and diet trends in the United States.

Data and Assumptions

At the retail level, three different agencies can do testing of products. These three agencies are the retail firm, a private food safety company (hired by the retail firm), and the USDA. These three agencies have the option to test certain meats for contamination as well as checking on the SOPs of the firm. While most retail firms do not use microbial testing themselves, their employees are trained in “HACCP-based” programs to help prevent and reduce pathogen growth and contamination. Retail firms also hire private firms to do checks to ensure that SOPs are being practiced correctly and also to do some microbial testing. All agencies do random checks every one to three months. The agency employee collects random microbial data at any point determined to be most beneficial in pathogen reduction.

The retail model has total system costs consisting mainly of the quality loss and testing costs. The value of risk reduction can be a system cost or benefit, depending on whether microbial testing is done or not. If testing is done and control measures are adopted, the value of risk reduction is a benefit. The value of risk reduction is an additional system cost or compensation forgone in firms when there is no testing and intervention. In other words, when testing is done any agency intervention measures are implemented, the value of risk reduction is viewed as compensation for mitigating food safety risks.

At the retail level, samples were collected from four local supermarkets and one retail meat shop. These samples were collected by the Veterinary and Microbiology

Department at North Dakota State University (NDSU). Meats sampled were whole chickens, a beef cut, a pork cut, whole turkeys, a turkey cut, and ground turkey. Various brands, including store brands, were purchased to test. All products were raw and unfrozen and had no additives (e.g., spices or marinades) of any kind. Each store was visited for a five-day period to collect samples. Each week a new store was visited. Meat products were purchased at the store and transported to the lab on ice. Upon arrival to the lab, processing of each sample began immediately.

Table 3.2 shows the break down of the sample by meat type. A total of 456 samples were collected of which 133 came from beef products, 123 came from chicken products, 113 came from pork products, and 87 came from turkey products. Ground product poses a higher risk of foodborne illness because it requires more handling (grinding, processing, etc.) as compared to meat cuts. Ground products comprised 27 of the beef samples, 31 of the turkey samples and 21 of the pork samples. No chicken samples were ground product. A large portion of the turkey samples are ground. This might indicate higher levels of pathogens in turkey samples as compared to the other meat products.

Table 3.2. Breakdown of Samples by Meat Type.

	Meat Type			
	Beef	**Chicken**	**Pork**	**Turkey**
Total Number of Samples	133	123	113	87
Samples of ground product	27	0	21	31
Percent of samples that are ground product	20.3%	0%	18.58%	35.63%

Distribution of Risk Parameters

In reality, contamination does not necessarily occur in every product at the retail level due to the effectiveness of HACCP-based regulation at the retail level and other food safety measures. Before calculating the quality loss component, the probability of pathogen contamination, given a critical limit or tolerance level for each of the three pathogens, was calculated to reflect the risk assessment objectives and the actual risk of contamination.

Because of the relatively small number of product samples tested for the three pathogens, contamination data collected from the supermarkets formed the basis for 1000 simulated draws for each meat and pathogen type, following a binomial distribution depicting presence or absence of each pathogen. At five different tolerance levels (29%, 15%, 10%, 5% and 1%), the probability of contamination was estimated as $\theta_i = n_i/1000$, where n is the number of positive tests, and *i* is the type of pathogen.

To take into account the fact that retail products can be improperly handled, increasing the risk of a foodborne illness outbreak, a survival function is used to give a more accurate representation. An exponential probability distribution is used to model survival rates. The exponential distribution is a continuous distribution that is useful when calculating the area under a curve corresponding to some interval of time and provides a probability that the random variable will take on a certain value. For instance, the number of positive *Salmonella* samples over the period of shelf life given an average number of positive samples over the interval. The probability of the exponential random variable is given as $P(x \geq x_0) = e^{\wedge}(-x/\mu)$, where μ is the average number of occurrences in an interval, e is Euler's number, x is the number of occurrences in the interval, and x_0 is the value of interest. In this case, x_0 would be the number of occurrences that would violate the tolerance level (i.e., 290 positive tests from 1000 samples).

To estimate the probability that there is both pathogen presence and pathogen growth, the intersection of both events needs to be calculated to determine the new probability of contamination. In this study, we will assume that pathogen presence and pathogen growth are independent events because a product can test negative for pathogens but still have pathogen cultures that will grow if they are exposed to ideal conditions for growth. Also, the retail firm has no information on the testing and sampling practices of the processing firm. Thus, the retail firm must assume that the processor is providing a product that has tested negative for pathogen presence. Once this assumption is made, we can use the multiplication law to determine the probability of the intersection. The multiplication law states that $P(A \cap B) = P(A) * P(B)$, where A is the event of pathogen presence and B is the event of pathogen growth (Anderson, Sweeney, and Williams, 2003). Therefore, our new probability of contamination is $P(A \cap B) = \theta_{i*} P(x \geq x_0)$, where θ_i and $P(x \geq x_0)$ are as previously defined

Quality Loss

A quality loss function is used to estimate quality loss due to violations of performance standards. Quality loss could occur at any point along the processing, marketing, and consumption continuum. A Taguchi Loss Function with smaller-is-better characteristics is used to calculate quality loss. In the case of an integrated firm, quality loss only occurs at the final destination and is calculated based on deviations from a target value of zero.

The Taguchi Loss Function establishes a financial measure of user dissatisfaction with a product's performance as that performance deviates from a target tolerance level. The loss function is defined as

(1) $$L= (A_o/\Delta_o^2)\sigma^2 ,$$

where L is the quality loss, A_o is the welfare loss when the tolerance limit is violated, Δ_o is the tolerance limit, and σ^2 measures the variance of the quality of the product. In the smaller-is-better models, variance is sometimes measured as deviation from the target. Because the data were generated based on a binomial distribution (pathogen present or no pathogen), variance was calculated based on the formula for binomial distributions. The loss to society is composed of costs incurred by the producer and the customer. The producer is exposed to rejection costs, loss of future business, etc., while the consumer is exposed to food safety risks. Quality deviations from the target value of zero represent an implicit cost to the system; thus, shipments containing even minimal microbial pathogen content incur quality loss.

The welfare loss when the tolerance limit is violated is comprised of three major components. The first component is the loss imparted by decreasing demand when an outbreak occurs. Empirical evidence from Kay (2003) showed that decreasing demand is the most important component of the loss and it represents about 60% of the total loss that a firm can incur. Another component is the loss due to decrease in market turkey price. This price decrease represents about 4.2% (Kay 2003) of the total cost when there is an outbreak. The last component is the cost of recall. When there is an outbreak, the processing firm may recall all of that day's production, estimated as the total revenue for that day.

The welfare loss, A_o is an additive function of D, the recall impact on consumer demand, P_m, the impact on meat market price, and TR, the total revenue. Total revenue components of total output and price were modeled as stochastic variables. Total output was based on data collected from local retail meat shops and was put into a risktriang distribution with values of $156,250 for a high value, $75,000 for a low, and $98,125 for the most likely value. Price was simulated by taking the average monthly prices on each meat type for the years 1970 to 2004 and fitting those numbers to a distribution. Each meat type had a different distribution. The distributions were also truncated so that the software would not select a negative number for price. In the model, it is assumed that if a test is made with a sampling intensity of at least two samples, (the minimum number of samples required to be taken per CCP during the study), the potential quality loss is reduced by 50%. This derives from one important model assumption that when the probability of contamination exceeds zero, there is a 50% reduction in quality loss if appropriate minimal testing and intervention are performed. This, in effect, is a cornerstone assumption in this study that HACCP is at least 50% effective. Assumptions on the effectiveness of HACCP have been reported by Antle (2000) and Knutson, et.al. (1995). Delphi survey results from the latter suggested that HACCP is only 20% effective, while the former assumed that prior safety level ranged from 50% to 90%. In addition, the FSIS assumed 10% to 100% effectiveness for HACCP as a basis for its regulatory impact assessment.

Value of Risk Reduction

When microbial testing is done by an agency where the probability of contamination is greater than zero, benefits result from risk reduction. The value of risk reduction could be greater than the total revenue because recall costs include total value of production, loss in market share value, and liability payments. The value of risk reduction is the additional benefit accruing to a firm which tests for pathogens and implements specific intervention strategy.

The measure of risk reduction compensates the retail firm when an agency tests for pathogens and implements control measures if the tolerance level is violated. It is a measure of the benefit derived from not shutting down due to an outbreak of a particular pathogen. Hence the value of risk reduction is a function of the testing decision and the sampling intensity and it estimates the portion of total revenue which is retained when an outbreak is prevented. It is mathematically defined as

(2) $$\pi_i = \theta_i * (TR) * \beta_i,$$

where π is the value of risk reduction, and β is an element of the set {0, 1} which is a binary testing decision variable, where 1 equals the optimal decision is to test for pathogens and 0 otherwise.

Testing Costs

Testing for pathogens occurs at various times randomly by any agency. Testing may be done at different intensity levels (number of samples) and/or different tolerance levels (number of pathogen at which the product is still considered safe for human consumption). These costs were measured for each agency. Conventional wisdom is that higher sampling intensities and testing decreases the probability of producing and selling contaminated food products.

Testing costs include three major components: the utilities cost for each agency, associated labor costs for each agency, and the cost of pathogen testing in laboratories outside the retail firm. Factors earlier mentioned were taken into consideration to arrive at a labor cost for all types of pathogen testing at $14 per test. However, labor costs can vary between $8 and $20 per test. Hence labor costs were represented as a stochastic variable in the model, especially because USDA inspection agents may require more testing if food safety problems persist. The cost of utilities for each agency is assumed fixed at $36 per test.

The cost of *Salmonella* and *Campylobacter* testing can vary with the type of test used, ranging between $10 and $14 per test. Like labor cost, the cost of *Salmonella* and *Campylobacter* testing is also represented by a stochastic variable to account for uncontrollable risk factors which lead to the variability in cost figures. Both variables were assumed to be normally distributed.

The cost of *E. coli* testing can vary from $100 to $200 per test, depending on the type of test, with the average price being $150. Like labor cost and *Salmonella* and *Campylobacter* test, the *E. coli* tests were represented by a stochastic variable to account for uncontrollable risk factors which lead to the variability in cost figures. *E. coli* tests were assumed to be a risk triangle distribution with $100 being the lowest cost, $200 being the highest possible cost and $150 being the most likely cost of testing.

Total testing costs, C, for each pathogen type are estimated by using the following equation:

(3) $$C_i = (L_i + U_i + T_i)*n_i*\beta_i,$$

where L is the labor cost for collecting and preparing product samples, U is the utilities cost, T is the cost of pathogen testing, and n, i and β are as previously defined.

Total Economic Costs

Total economic costs associated with the retail meat sector are composed of the value of risk reduction, testing and sampling costs, and the quality loss. The direct cost components include the testing costs, and utilities and labor costs. The indirect cost component accounts for quality loss incurred when there is a violation of the tolerance level. The value of risk reduction was considered a benefit in this study, because it is the cost avoided when adequate testing for pathogens is performed and an intervention strategy is implemented. Hence the total system cost, TC, less the cost of inputs and other fixed costs of HACCP or HACCP-based food safety intervention strategy, is defined as

(4) $$TC = \sum L_i + C_i - \pi_i.$$

A net benefit function is developed around equation 4, by subtracting equation 4, as well as the product input costs and the fixed production costs of HACCP, from the total revenue from the particular product. Hence the net benefit function is

(5) $$NB(\beta,n) = p * Y - TC(\beta,n),$$

where p is the product price and Y is the total product, and n and β are as previously defined.

Stochastic Optimization Model and the Risk Premium

The risk premium measures the difference between the expected value of the net benefit and its associated certainty equivalent. Based on the expected utility concept, risk averters would prefer a certain return to a risky investment with an uncertain but equal expected return. If we define the certainty equivalent as the certain amount of money that makes the risk averse decision maker indifferent between the certain cash and the gamble whose expected monetary value is equal to the certain cash, then the risk premium is the addition amount required to compensate the risk-averse decision maker from taking the risk. The effect of the market risk is captured with an expected utility model. Following Pratt (1964), the risk premium (ξ) is the difference between the certainty equivalent (CE) and the expected value of the net benefit such that

(6) $$U(CE) = U[E(NB)-\xi(NB)] = E[U(NB)].$$

The risk premium is a function of the level of risk aversion and is measured by the curvature of the utility function and the level of risk.

A stochastic optimization model for retail facilities using three alternative mitigation strategies was developed. The utility maximization framework uses an expo-power utility function (Saha, 1993) to quantify a risk premium. The expo-power utility function is a flexible form that does not impose any predetermined risk preference structure on risk attitudes, and may be used to model both absolute and relative risk aversion.

The model chooses the optimal testing intensity and strategy that maximizes the firm's utility. The model assumes a linear net benefit function that estimates benefits above certain variable costs (testing costs and quality loss). The objective function can be expressed by the following equation:

(7) Maximize $E[U(NB)] = E(\lambda\text{-e-}\alpha NB(\beta,n)\delta),\ )$, for all $\delta\neq 0, \alpha\neq 0, \alpha\delta>0$,

subject to

$$0\leq n \leq 4$$

$$\beta \in \{0,1\},$$

where λ is usually a positive parameter, while α and δ are parameters that affect absolute and relative risk aversion of the utility function. The first constraint reflects that fact that a retail facility could be inspected by the USDA, the private firm, or itself at least four times per month or once per week. The second constraint is the binary testing decision variable (1 to test, and 0 otherwise).

The expo-power utility function is quasi-concave for all NB > 0. Necessary and sufficient conditions for concavity exist if $\delta - \delta\alpha NB^{\delta} - 1 \leq 0$, and $\delta \leq 0$, respectively. This function exhibits decreasing absolute risk aversion if $\delta < 1$, constant absolute risk aversion if $\delta = 1$, and increasing absolute risk aversion is $\delta > 1$. To ensure regularity in the utility function, values for λ, α, and δ were initially set at 2, 0.00005 and 0.04, respectively, the latter to confer decreasing absolute risk aversion, since many retail facilities are more likely to change risk preferences as wealth levels increase. Additional analyses were performed to determine optimal testing decisions and sampling intensities under constant absolute risk aversion because some retail facilities are conservative and would not change risk preferences even as their wealth levels increase over time.

CHAPTER 4. RESULTS
Objective 1

Pathogen contamination data from retail supermarkets were used to calculate contamination probabilities at five different tolerance levels for four types of meat. The pathogen contamination probabilities were calculated assuming tolerance levels of 29%, 15%, 10%, 5% and 1%. Table 4.1 shows that *Salmonella* contamination is prevalent in turkey at the 5% and 1% tolerance levels and in chicken at the 1% tolerance level. Beef and pork showed no probability of *Salmonella* contamination.

Table 4.1. Probability of *Salmonella* Contamination by Each Meat Type Using Survival Analysis.

Meat Type	29% Tolerance	15% Tolerance	10% Tolerance	5% Tolerance	1% Tolerance
Beef	0.0000	0.0000	0.0000	0.0000	0.0000
Chicken	0.0000	0.0000	0.0000	0.0000	0.0147
Pork	0.0000	0.0000	0.0000	0.0000	0.0000
Turkey	0.0000	0.0000	0.0000	0.0710	0.0544

As expected, Table 4.2 shows that *E. coli* is most prominent in beef (0.6967 at a 29% tolerance level). This implies that 69.67% of beef samples will have positive *E. coli* prevalence if the performance standard is set at 29%. It also shows there is a probability of *E. Coli* contamination at all tolerance levels and across all meat types.

Table 4.2. Probability of *E. coli* Contamination by Each Meat Type Using Survival Analysis.

Meat Type	29% Tolerance	15% Tolerance	10% Tolerance	5% Tolerance	1% Tolerance
Beef	0.6967	0.8142	0.8602	0.9085	0.9489
Chicken	0.3922	0.5324	0.5878	0.6466	0.6963
Pork	0.4147	0.5538	0.6087	0.6667	0.7158
Turkey	0.2913	0.4342	0.4918	0.5536	0.6064

Campylobacter is similar to *Salmonella* in that the probabilities are low and usually only present in the lowest tolerance levels (Table 4.3). However, chicken shows probabilities of *Campylobacter* contamination at 15%, 10%, 5%, and 1% tolerance levels.

Table 4.3. Probability of *Campylobacter* Contamination by Each Meat Type Using Survival Analysis.

Meat Type	29% Tolerance	15% Tolerance	10% Tolerance	5% Tolerance	1% Tolerance
Beef	0.0000	0.0000	0.0000	0.0000	0.0272
Chicken	0.0000	0.0770	0.1259	0.1876	0.2482
Pork	0.0000	0.0000	0.0000	0.0000	0.0123
Turkey	0.0000	0.0000	0.0000	0.0171	0.0627

Quality Loss Estimates

Quality loss estimates are presented in Tables 4.4 and 4.5. Quality loss estimates are zero where the probability of a certain meat type testing positive for contamination was zero. Thus, at the 29%, 15%, 10%, and 5% tolerance levels the quality losses are zero for beef showing *Campylobacter*, pork showing *Campylobacter*, and chicken showing *Salmonella*. The estimates are also zero at the 29%, 15%, and 10% tolerance levels for turkey showing *Campylobacter* and *Salmonella*, as well as chicken showing *Campylobacter* at the 29% tolerance level.

Table 4.4 shows the estimate without contamination reduction, or the quality loss before PR/HACCP is used as a mitigation strategy. As expected, quality loss estimates increased as the tolerance levels tightened. The highest quality loss values are always found at the 1% tolerance level. This is an indication that stricter compliance could lead to increased quality loss. The highest estimates of quality loss are found where the probability of pathogen contamination is high for a particular meat type. Thus, the highest estimates are found across all meat types for *E. coli*.

Table 4.4. Quality Loss Estimates in Retail Without Contamination Reduction (in $/day).

Meat Type/Pathogen	29% Tolerance	15% Tolerance	10% Tolerance	5% Tolerance	1% Tolerance
Beef/*Campylobacter*	0	0	0	0	451000
Beef/*E.coli*	185,270	809,000	1,920,000	8,130,000	8,490,000
Chicken/*Campylobacter*	0	274,000	1,010,000	6,020,000	7,960,000
Chicken/*E.coli*	370,708	1,880,000	4,670,000	20,600,000	22,100,000
Chicken/*Salmonella*	0	0	0	0	138,000
Pork/*Campylobacter*	0	0	0	0	11,000
Pork/*E.coli*	30,182	151,000	373,000	1,630,000	1,750,000
Turkey/*Campylobacter*	0	0	0	122,000	448,000
Turkey/*E.coli*	335,937	1,870,000	4,770,000	21,500,000	23,500,000
Turkey/*Salmonella*	0	0	0	69,800	347,000

*See Table 3.1 for approximate amount of product sold each day.

Table 4.5 shows the estimate with the 50% contamination reduction, or the quality loss after PR/HACCP implementation. The same holds true for these estimates. Higher tolerance levels increase the quality loss. *E. coli* is especially high because of its prominent prevalence all of the meat types. For *E. coli*, pork has the lowest quality loss values. This could be due to the fact that pork accounted for a smaller portion of a firm's revenue than the other meats.

Estimates of Value of Risk Reduction

The value of risk reduction places a monetary value on the amount of food safety risk reduced each time product testing occurs and corrective measures are implemented. Table 4.6 shows the value of risk reduction across all tolerance levels. These values are the highest among all meat types for *E. coli*. The estimates of the value of risk reduction for *E. coli* were by far the highest in beef with values of $199.97/day at the 29% level, $233.72/day at the 15% level, $246.91/day at the 10% level, $260.77/day at the 5% level, and \$272.37/day at the 1% level. This is because the prevalence of *E. coli* was highest in beef. The next highest estimates came from testing for *E. coli* in pork.

Table 4.5. Quality Loss Estimates in Retail with Contamination Reduction (in \$/day).

Meat Type/Pathogen	29% Tolerance	15% Tolerance	10% Tolerance	5% Tolerance	1% Tolerance
Beef/*Campylobacter*	0	0	0	0	225,500
Beef/*E. coli*	92,634.99	404,500	960,000	4,065,000	4,245,000
Chicken/*Campylobacter*	0	137,000	505,000	3,010,000	3,980,000
Chicken/*E. coli*	185,353.845	940,000	2,335,000	10,300,000	11,050,000
Chicken/*Salmonella*	0	0	0	0	69,000
Pork/*Campylobacter*	0	0	0	0	5,500
Pork/*E. coli*	15,090.89	75500	186,500	815,000	875,000
Turkey/*Campylobacter*	0	0	0	61,000	224,000
Turkey/*E. coli*	167,968.59	935,000	2,385,000	10,750,000	11,750,000
Turkey/*Salmonella*	0	0	0	34,900	173,500

*See Table 3.1 for approximate amount of product sold each day.

This also follows suit because pork had the next highest *E. coli* prevalence. The values for pork were \$84.74 at a 29% tolerance level, \$113.18 at a 15% tolerance level, \$124.38 at a 10% tolerance level, \$136.25 at a 5% tolerance level, and \$146.27 at a 1% tolerance level. *E. coli* testing for chicken had very similar risk reduction values. Typically, the value of risk reduction for chicken was \$3 to \$4 less than the value of risk reduction for pork at each tolerance level. *E. coli* testing for turkey had the lowest value of risk reduction. The values were \$50.90 at a 29% level, \$75.89 at a 15% tolerance level, \$85.96 at a 10% tolerance level, \$96.76 at a 5% tolerance level, and \$105.98 at a 1% tolerance level. Overall, the value of risk reduction estimates was lower than the quality loss estimates, when compared on a monthly basis.

Campylobacter testing for beef only provided risk reduction at the 1% tolerance level. The value of risk reduction was \$19.50. For chicken and *Campylobacter*, the values of risk reduction were $15.90 at a 15% level, $26.00 at a 10% tolerance level, $38.75 at the 5 % tolerance level and $51.27 at a 1% tolerance level. *Campylobacter* testing for pork provides risk reduction at only a 1% tolerance level with a value of $2.52. Turkey showed risk reduction from *Campylobacter* testing at 5% and 1% tolerance levels with values of $0.25 and $0.91, respectively.

Salmonella testing for chicken only provided risk reduction at a 1% tolerance level with a value of $10.73. Turkey showed risk reduction from testing at the 5% and 1% levels with values of $0.16 and $0.79, respectively.

Table 4.6. Value of Risk Reduction at Different Tolerance Levels ($/lb).

Meat Type/Pathogen	29% Tolerance	15% Tolerance	10% Tolerance	5% Tolerance	1% Tolerance
Beef/*Campylobacter*	0.00	0.00	0.00	0.00	19.50
Beef/*E. coli*	199.97	233.72	246.91	260.77	272.37
Chicken/*Campylobacter*	0.00	15.90	26.00	38.75	51.27
Chicken/*E. coli*	81.00	109.97	121.41	133.55	143.82
Chicken/*Salmonella*	0.00	0.00	0.00	0.00	10.73
Pork/*Campylobacter*	0.00	0.00	0.00	0.00	2.52
Pork/*E. coli*	84.74	113.18	124.38	136.25	146.27
Turkey/*Campylobacter*	0.00	0.00	0.00	0.25	0.91
Turkey/*E. coli*	50.90	75.89	85.96	96.76	105.98
Turkey/*Salmonella*	0.00	0.00	0.00	0.16	0.79

Objective 2

Optimal Intervention Strategies at the Retail Level

The results for *Salmonella* pathogen contamination (Tables 4.7 and 4.8) show that testing is only optimal at performance standards for the 5% and 1% tolerance levels. This is consistent with the idea that the probabilities for *Salmonella* contamination are low; therefore, it is only optimal to test at the lowest tolerance levels. Because our data showed no probabilities for *Salmonella* contamination in beef or pork, models for turkey and chicken were the only ones analyzed. Under constant absolute risk aversion (CARA), when testing was performed at the 1% tolerance level only, turkey had an optimal strategy of two tests per month by the retail firm, or strategy 3, and chicken had an optimal strategy of two tests per month by the private firm, or strategy 2.

Table 4.7. Optimal Intervention Strategies for *Salmonella* Testing and HACCP Implementation at the Retail Level Under Constant Absolute Risk Aversion.

	5% Tolerance		1% Tolerance	
Meat Type	Test Decision	# of Samples	Test Decision	# of Samples
Chicken	0	0	USDA	2
Turkey	0	0	Retail	2

Under decreasing absolute risk aversion (DARA), chicken had an optimal strategy of one retail sample per month at the 1% tolerance level. Turkey had an optimal strategy at the 1% tolerance level of two retail samples per month or two USDA samples per month. At the 5% tolerance level, the optimal strategies for turkey were three samples per month by the retail, one sample per month by the private firm, or one sample by the USDA per month.

Testing for *Campylobacter* (Tables 4.9 and 4.10) had an optimal strategy only under DARA at the 1% level. These tests were optimal for beef and turkey only. This result was unexpected because the prevalence of *Campylobacter* was higher in chicken than any of the other meat types. For beef, the optimal strategies were to have either the private firm or the USDA test four times each month. For turkey, the optimal strategy was to test only once per month by the retail firm.

Table 4.8. Optimal Intervention Strategies for *Salmonella* Testing and HACCP Implementation at the Retail Level Under Decreasing Absolute Risk Aversion.

	5% Tolerance		1% Tolerance	
Meat Type	Test Decision	# of Samples	Test Decision	# of Samples
Chicken	0	0	Retail	1
Turkey	Retail	3	Retail	2
	Private	1	Private	2
	USDA	1		

Table 4.9. Optimal Intervention Strategies for *Campylobacter* Testing and HACCP Implementation at the Retail Level Under Decreasing Absolute Risk Aversion.

	1% Tolerance	
Meat Type	Test Decision	# of Samples
Beef		
	Private	4
	USDA	4
Chicken		
	0	0
Pork		
	0	0
Turkey	Retail	1

Under CARA, testing was only optimal for pork at a 1% tolerance level. It was optimal to test two times per month by the private firm or once per month by the USDA. As expected, testing for *E. coli* in beef was shown to be optimal at all tolerance levels under CARA. Tables 4.11 and 4.12 show the optimal strategies for *E. coli* testing for beef. The optimal strategies under CARA for beef are to test once each month by the retail level or four times per month by the private firm at the 29% level; to test three times per month by the retail level or two times per month by the USDA for both the 15% and 10% tolerance levels; to test four times per month by the retail level; three times per month by the private firm; or two times by the USDA at the 5% level; and finally, at the 1% level to test four times per month at the retail level or private firm or twice per month by the USDA.

Table 4.10. Optimal Intervention Strategies for *Campylobacter* Testing and HACCP Implementation at the Retail Level Under Constant Absolute Risk Aversion.

	1% Tolerance	
Meat Type	Test Decision	# of Samples
Beef	0	0
Chicken	0	0
Pork	Private USDA	2 1
Turkey	0	0

Under DARA, the optimal strategies for beef (Table 4.12) are to test once per month by the retail or four times per month by a private firm for both the 29% and 15% tolerance levels. Testing at the 10% level is optimal for either once per month by the retail or twice per month by the private firm. At the 5% level, optimal strategies for beef are to test three times per month by the retail level, two times per month by a private firm, or once each month by the USDA. At the 1% level, it is to test four times per month by the retail level or once per month by the private firm.

Table 4.11. Optimal Intervention Strategies of *E. coli* Testing for Beef at the Retail Level Under Constant Absolute Risk Aversion.

		Beef		
		USDA (Strategy 1)	**Private (Strategy 2)**	**Retail (Strategy 3)**
29% Tolerance Level	Test Decision	0	1	1
	# of Samples	0	4	1
15% Tolerance Level	Test Decision	1	0	1
	# of Samples	2	0	3
10% Tolerance Level	Test Decision	1	0	1
	# of Samples	2	0	3
5% Tolerance Level	Test Decision	1	1	1
	# of Samples	2	3	4
1% Tolerance Level	Test Decision	1	1	1
	# of Samples	2	4	4

For pork, the optimal *E. coli* testing strategies under DARA (Table 4.13) are to test three times per month by the retail level, twice each month by the private firm or one time each month by the USDA at the 29% level. At the 15% level, the optimal strategy is to have two tests per month by the USDA, one per month by the private firm, or three tests per month by the retail. At 10%, the optimal is three tests per month by the private firm or one each month by the retail firm. For the 5% level, it is optimal to test three times per month by retail or one by the USDA per month, and at the 1% level, it is optimal to test one time per month at the retail level, four times per month by the private firm, or one time per month by the USDA.

Table 4.12. Optimal Intervention Strategies of *E.coli* Testing for Beef at the Retail Level Under Decreasing Absolute Risk Aversion.

Beef				
		USDA (Strategy 1)	**Private (Strategy 2)**	**Retail (Strategy 3)**
29% Tolerance Level	Test Decision	0	1	1
	# of Samples	0	4	1
15% Tolerance Level	Test Decision	0	1	1
	# of Samples	0	4	1
10% Tolerance Level	Test Decision	0	1	1
	# of Samples	0	2	1
5% Tolerance Level	Test Decision	1	1	1
	# of Samples	1	2	3
1% Tolerance Level	Test Decision	0	1	1
	# of Samples	0	1	4

Table 4.14 shows the optimal *E. coli* testing intervention strategies for pork under CARA. The optimal testing strategies at the 29% level are three times per month by the USDA, once per month by the private firm, or four times each month by the retail firm. At the 15% level, the optimal strategies are four times per month by the retail or USDA, or three times per month by the private firm. The 10% level shows twice per month by the USDA, once per month by the private firm, or three times per month by the retail firm. At the 5% level, the only strategy was to test three times per month by the retail firm, and at the 1% level, it was optimal to test only one time per month by the USDA. As the tolerance level tightens, the testing intensity decreases. This indicates that tighter tolerance levels are more costly to the retail firms because of product loss when samples are rejected.

Table 4.13. Optimal Intervention Strategies of *E. coli* Testing for Pork at the Retail Level Under Decreasing Absolute Risk Aversion.

	Pork			
		USDA (Strategy 1)	**Private (Strategy 2)**	**Retail (Strategy 3)**
29% Tolerance Level	Test Decision	1	1	1
	# of Samples	1	2	3
15% Tolerance Level	Test Decision	1	1	1
	# of Samples	2	1	3
10% Tolerance Level	Test Decision	0	1	1
	# of Samples	0	3	1
5% Tolerance Level	Test Decision	1	0	1
	# of Samples	1	0	3
1% Tolerance Level	Test Decision	1	1	1
	# of Samples	1	4	1

The results for chicken with *E. coli* testing under DARA are shown in Table 4.15. At the 29% level, optimal *E. coli* testing strategies are four times per month by the USDA, once per month by the private firm, or twice each month by the retail firm. At the 15% level, it is shown to be any of the strategies as long as the testing is done twice per month. The 10% level shows optimal testing from three times per month by the USDA or twice each month by the private firm. The 5% level shows four times per month by the retail, four times per month by the private firm, or three times each month by the USDA. At the 1% level, there is only one strategy of testing one time per month by the retail firm. Under CARA, the results for *E. coli* testing in chicken are shown in Table 4.16. The 29% level shows an optimal strategy of either one test by the USDA or one test by the private firm per month. The 15% level shows only one optimal result of two tests per month by the USDA and the 10% level has only one optimal test of two tests per month by the private firm. The 5% and 1% levels show no testing is required. This could be explained by the fact that there is less handling of raw chicken products in retail meat shops, thus it is not optimal to test at tighter levels.

Table 4.14. Optimal Intervention Strategies of *E. coli* Testing for Pork at the Retail Level Under Constant Absolute Risk Aversion.

		Pork		
		USDA (Strategy 1)	**Private (Strategy 2)**	**Retail (Strategy 3)**
29% Tolerance Level	Test Decision	1	1	1
	# of Samples	3	1	4
15% Tolerance Level	Test Decision	1	1	1
	# of Samples	4	3	4
10% Tolerance Level	Test Decision	1	1	1
	# of Samples	2	1	3
5% Tolerance Level	Test Decision	0	0	1
	# of Samples	0	0	3
1% Tolerance Level	Test Decision	1	0	0
	# of Samples	1	0	0

The results for turkey (Tables 4.17 and 4.18) show that it is not optimal to test for *E. Coli* at the 5% and 1% tolerance levels under both CARA and DARA. This could be because turkey yielded lower value of risk reduction estimates and also because, like chicken at the retail level, little processing or grinding is done with turkey.

Table 4.15. Optimal Intervention Strategies of *E. coli* Testing for Chicken at the Retail Level Under Decreasing Absolute Risk Aversion.

		Chicken		
		USDA (Strategy 1)	**Private (Strategy 2)**	**Retail (Strategy 3)**
29% Tolerance Level	Test Decision	1	1	1
	# of Samples	4	1	2
15% Tolerance Level	Test Decision	1	1	1
	# of Samples	2	2	2
10% Tolerance Level	Test Decision	1	1	0
	# of Samples	3	2	0
5% Tolerance Level	Test Decision	1	1	1
	# of Samples	3	4	4
1% Tolerance Level	Test Decision	0	0	1
	# of Samples	0	0	1

Under DARA, the 29% level shows optimal strategies of either one test per month by the retail level or two tests per month by the private firm. At the 15% level the optimal strategies are either three tests per month by the USDA or one test per month by the retail firm, and at the 10% level the optimal strategies are once per month by the retail firm, once per month by the private firm or four times per month by the USDA. As previously mentioned, no testing is required at the 5% and 1% levels.

Under CARA, the optimal strategies at the 29% and 15% levels were to test once per month by the retail level or once per month by the private firm. At the 10% level it was optimal to test once per month by the retail or three times per month by the USDA. As previously mentioned, no testing is required at the 5% and 1% levels.

Table 4.16. Optimal Intervention Strategies of *E. coli* Testing for Chicken at the Retail Level Under Constant Absolute Risk Aversion.

		Chicken		
		USDA (Strategy 1)	**Private (Strategy 2)**	**Retail (Strategy 3)**
29% Tolerance Level	Test Decision	1	1	0
	# of Samples	1	1	0
15% Tolerance Level	Test Decision	1	0	0
	# of Samples	2	0	0
10% Tolerance Level	Test Decision	0	1	0
	# of Samples	0	2	0
5% Tolerance Level	Test Decision	0	0	0
	# of Samples	0	0	0
1% Tolerance Level	Test Decision	0	0	0
	# of Samples	0	0	0

Objective 3

Stochastic Dominance Analysis

The three strategies were compared using stochastic dominance methodologies for alternative meat types and pathogens. Stochastic dominance has been used extensively to compare risky alternatives. These alternatives were compared using SIMETAR software.

Upper and lower risk aversion coefficients were used. The lower risk aversion coefficient (Lower RAC) was 0.000001. This number represents firms that would be very risk neutral, meaning that they are not concerned with risk. The upper risk aversion coefficient (Upper RAC) was 0.1. This number represents a firm that is extremely risk averse, meaning that it is very concerned with risk and will pay a premium to reduce risk. This wide range of risk attitudes helps to evaluate the robustness of the results.

Table 4.17. Optimal Intervention Strategies of *E. coli* Testing for Turkey at the Retail Level Under Decreasing Absolute Risk Aversion.

Turkey				
		USDA (Strategy 1)	**Private (Strategy 2)**	**Retail (Strategy 3)**
29% Tolerance Level	Test Decision	1	1	0
	# of Samples	1	2	0
15% Tolerance Level	Test Decision	1	0	1
	# of Samples	3	0	1
10% Tolerance Level	Test Decision	1	1	1
	# of Samples	4	1	1
5% Tolerance Level	Test Decision	0	0	0
	# of Samples	0	0	0
1% Tolerance Level	Test Decision	0	0	0
	# of Samples	0	0	0

The analysis considered the entire set of strategies and tolerance levels for each meat type that could possibly be contaminated with *E. coli* and also for turkey that could possibly be contaminated with *Salmonella*. The other combinations of meat types and pathogens were not relevant because of low or no pathogen prevalence or because there was only one clear strategy for that specific meat and pathogen. The results of the stochastic dominance analysis show that either strategies two or three were highly preferred, except in the case of turkey with possible *E. coli* contamination where the preferred strategy was strategy one using a 10% tolerance level.

Table 4.18. Optimal Intervention Strategies of *E. coli* Testing for Turkey at the Retail Level Under Constant Absolute Risk Aversion.

		Turkey		
		USDA (Strategy 1)	**Private (Strategy 2)**	**Retail (Strategy 3)**
29% Tolerance Level	Test Decision	0	1	1
	# of Samples	0	1	1
15% Tolerance Level	Test Decision	0	1	1
	# of Samples	0	1	1
10% Tolerance Level	Test Decision	1	0	1
	# of Samples	3	0	1
5% Tolerance Level	Test Decision	0	0	0
	# of Samples	0	0	0
1% Tolerance Level	Test Decision	0	0	0
	# of Samples	0	0	0

Table 4.19 shows the comparison of optimal intervention strategies for beef products under *E. coli* testing. For *E. coli* testing on beef, the top seven ranked strategies were to use strategy two or strategy three. All of the strategy ranks were the same among the risk neutral set and the risk averse set. Of those top seven ranked strategies, two had a 1% tolerance level; two had a 5% tolerance level; and 29%, 15%, and 10% were the tolerance levels of the remaining three. Strategy one was overwhelmingly the least preferred, having all but one of its strategies tie for the least preferred. The top-ranked preference was to use strategy three, or voluntary HACCP, at a 1% tolerance level. This

reflects the high value of risk reduction when testing for *E. coli* in beef. However, it may be appropriate to compare the value of risk reduction and quality loss as performance standards are tightened.

Table 4.19. Stochastic Dominance Comparison of Intervention Strategies for Beef Products Under *E. coli* Testing.

Efficient Set Based on SDRF at		Efficient Set Based on SDRF at	
Lower RAC	**0.000001**	Upper RAC	**0.1**
Name	Level of Preference	Name	Level of Preference
Strategy 3 @ 1%	Most Preferred	Strategy 3 @ 1%	Most Preferred
Strategy 2 @ 10%	2nd Most Preferred	Strategy 2 @ 10%	2nd Most Preferred
Strategy 2 @ 15%	3rd Most Preferred	Strategy 2 @ 15%	3rd Most Preferred
Strategy 2 @ 29%	4th Most Preferred	Strategy 2 @ 29%	4th Most Preferred
Strategy 3 @ 5%	5th Most Preferred	Strategy 3 @ 5%	5th Most Preferred
Strategy 2 @ 5%	6th Most Preferred	Strategy 2 @ 5%	6th Most Preferred
Strategy 2 @ 1%	7th Most Preferred	Strategy 2 @ 1%	7th Most Preferred
Strategy 1 @ 5%	8th Most Preferred	Strategy 1 @ 5%	8th Most Preferred
Strategy 3 @ 10%	9th Most Preferred	Strategy 3 @ 10%	9th Most Preferred
Strategy 3 @15%	10th Most Preferred	Strategy 3 @15%	10th Most Preferred
Strategy 3 @29%	11th Most Preferred	Strategy 3 @29%	11th Most Preferred
Strategy 1 @ 29%	12th Most Preferred	Strategy 1 @ 29%	12th Most Preferred
Strategy 1 @ 15%	12th Most Preferred	Strategy 1 @ 15%	12th Most Preferred
Strategy 1 @ 10%	12th Most Preferred	Strategy 1 @ 10%	12th Most Preferred
Strategy 1 @ 1%	12th Most Preferred	Strategy 1 @ 1%	12th Most Preferred

Figure 4.1 shows the value of risk reduction as compared to the quality loss for beef with *E. coli* contamination. This shows that quality loss for beef is high when testing for *E. coli*. It is higher than the value of risk reduction for tolerance levels of 15%, 10%, 5%, and 1%. The 29% tolerance level was the only level where the value of risk reduction exceeded the quality loss. The preferred strategy was to test at a 1% tolerance level because the value of risk reduction was highest at the 1% level, so it would appear that we have conflicting results. However, quality loss reflects economic losses and not accounting losses, thus the firm may still profit by testing at a 1% tolerance level. These results suggest that tightening performance standards to lower than 15% may not be cost-effective, as this could increase quality loss.

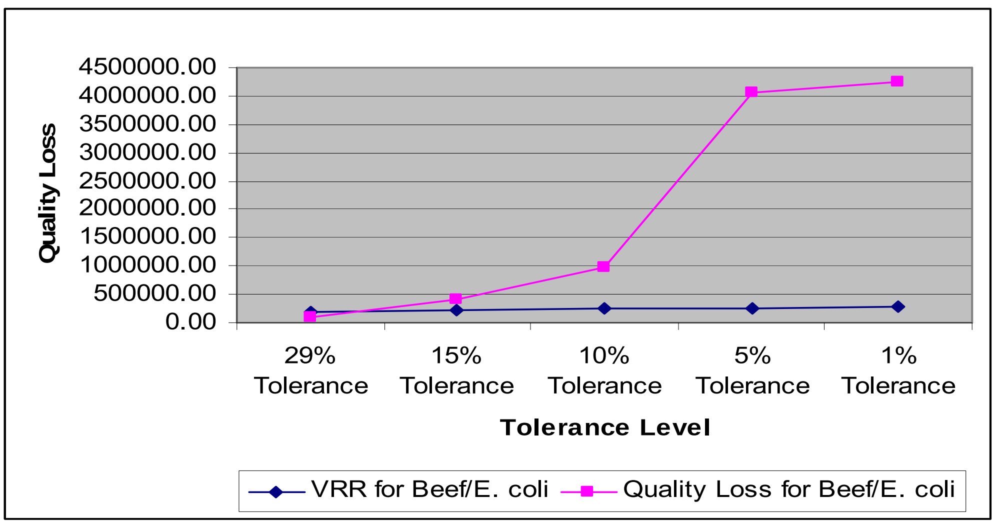


Figure 4.1. Comparison of Quality Loss and Value of Risk Reduction for Beef with *E. coli* Contamination.

The stochastic dominance comparisons of the optimal intervention strategies for chicken products under *E. coli* testing are shown in Table 4.20. *E. coli* testing in chicken shows that the top seven ranked preferences were a mix of all three strategies. All of the ranks for the strategies were identical between the risk averse set and the risk neutral set, indicating a robust preference for strategy three. Two preferences were strategy two; two preferences were strategy one; and three preferences were strategy three. In narrowing the top ranked to the top four, the strategies that were best were either two or three. The tolerance levels were all 15% or lower in the top seven ranked preferences.

Table 4.20. Stochastic Dominance Comparison of Intervention Strategies for Chicken Products Under *E. coli* Testing.

Efficient Set Based on SDRF at		Efficient Set Based on SDRF at	
Lower RAC	**0.000001**	Upper RAC	**0.1**
Name	Level of Preference	Name	Level of Preference
Strategy 3 @ 5%	Most Preferred	Strategy 3 @ 5%	Most Preferred
Strategy 2 @ 5%	2nd Most Preferred	Strategy 2 @ 5%	2nd Most Preferred
Strategy 3 @ 15 %	3rd Most Preferred	Strategy 3 @ 15 %	3rd Most Preferred
Strategy 3 @ 1%	4th Most Preferred	Strategy 3 @ 1%	4th Most Preferred
Strategy 1 @ 5%	5th Most Preferred	Strategy 1 @ 5%	5th Most Preferred
Strategy 2 @10%	6th Most Preferred	Strategy 2 @10%	6th Most Preferred
Strategy 1 @ 10%	7th Most Preferred	Strategy 1 @ 10%	7th Most Preferred
Strategy 2 @ 15%	8th Most Preferred	Strategy 2 @ 15%	8th Most Preferred
Strategy 1 @ 15%	9th Most Preferred	Strategy 1 @ 15%	9th Most Preferred
Strategy 2 @ 29%	10th Most Preferred	Strategy 2 @ 29%	10th Most Preferred
Strategy 3 @ 29%	11th Most Preferred	Strategy 3 @ 29%	11th Most Preferred
Strategy 2 @ 10%	11th Most Preferred	Strategy 2 @ 10%	11th Most Preferred
Strategy 1 @ 29%	13th Most Preferred	Strategy 1 @ 29%	13th Most Preferred
Strategy 2 @ 1%	14th Most Preferred	Strategy 2 @ 1%	14th Most Preferred
Strategy 1 @ 1%	Least Preferred	Strategy 1 @ 1%	Least Preferred

The comparison of quality loss and the value of risk reduction for chicken when testing for *E. coli* (shown in Figure 4.2) are similar to the previous comparison with beef. The quality loss is greater than the value of risk reduction at the 15%, 10%, 5%, and 1% levels. However, unlike the beef comparison, the chicken shows that at a 29% tolerance level, the value of risk reduction is just enough to cover quality loss. The preferred ranking for chicken when testing for *E. coli* was to use a 5% tolerance level. The quality loss being much higher than the value of risk reduction at the 5% level can again be explained by the fact that the quality loss reflects the implicit costs, thus testing using a 5% tolerance level does not mean an accounting loss, but only an economic loss. However, the results suggest that it may not be cost-effective to tighten performance standards below 29% because of increasing quality loss.

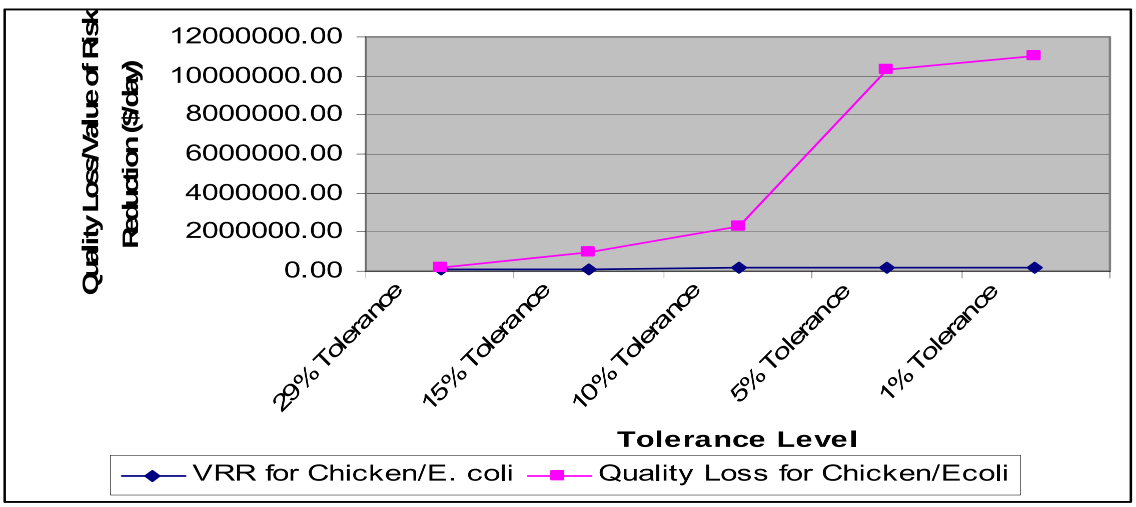


Figure 4.2. Comparison of Quality Loss and Value of Risk Reduction for Chicken with *E. coli* Contamination.

The stochastic dominance results for comparing the optimal intervention strategies for pork product under *E. coli* testing are shown in Table 4.21. *E. coli* testing in pork shows the top seven ranked preferences were a mix of all three strategies. All of the ranks for the strategies were identical between the risk averse set and the risk neutral set. The top seven ranked preferences showed a mix of all three strategies, however, the top five ranked preferences were all using either strategy two or three. The range of tolerance levels was very wide. This was perhaps because of the low amount of revenue generated by pork for a firm. The most preferred strategy was strategy two at a 1% tolerance level.

Table 4.21. Stochastic Dominance Comparison of Intervention Strategies for Pork Products Under *E. coli* Testing.

Efficient Set Based on SDRF at		Efficient Set Based on SDRF at	
Lower RAC	**0.000001**	Upper RAC	**0.1**
Name	Level of Preference	Name	Level of Preference
Strategy 2 @ 1%	Most Preferred	Strategy 2 @ 1%	Most Preferred
Strategy 3 @ 29%	2nd Most Preferred	Strategy 3 @ 29%	2nd Most Preferred
Strategy 3 @ 5%	3rd Most Preferred	Strategy 3 @ 5%	3rd Most Preferred
Strategy 2 @ 10%	4th Most Preferred	Strategy 2 @ 10%	4th Most Preferred
Strategy 3 @ 15%	5th Most Preferred	Strategy 3 @ 15%	5th Most Preferred
Strategy 1 @ 29%	6th Most Preferred	Strategy 1 @ 29%	6th Most Preferred
Strategy 1 @ 15%	7th Most Preferred	Strategy 1 @ 15%	7th Most Preferred
Strategy 1 @ 1%	8th Most Preferred	Strategy 1 @ 1%	8th Most Preferred
Strategy 3 @ 1%	8th Most Preferred	Strategy 3 @ 1%	8th Most Preferred
Strategy 1 @ 5%	10th Most Preferred	Strategy 1 @ 5%	10th Most Preferred
Strategy 2 @ 15%	11th Most Preferred	Strategy 2 @ 15%	11th Most Preferred
Strategy 2 @ 29%	12th Most Preferred	Strategy 2 @ 29%	12th Most Preferred
Strategy 1 @ 10%	13th Most Preferred	Strategy 1 @ 10%	13th Most Preferred
Strategy 3 @ 10%	13th Most Preferred	Strategy 3 @ 10%	13th Most Preferred
Strategy 2 @5%	13th Most Preferred	Strategy 2 @5%	13th Most Preferred

Figure 4.3 show a comparison of quality loss and value of risk reduction for pork when concerned with *E. coli* contamination yields similar results. This instance, however, only the 10%, 5% and 1% tolerance level estimates of quality loss exceed the value of risk reduction estimates. At the 29% and 15% levels, the value of risk reduction is greater than the quality loss. The preferred strategy for pork, however, was to use a 1% tolerance level. Again, this indicates an economic loss, but not necessarily an accounting loss. Once again, the results suggest that it may not be cost-effective to tighten standards below 15%.

Table 4.22 shows the stochastic dominance results for comparing the optimal intervention strategies for turkey products under *E. coli* testing. Turkey was the anomaly of the sets. *E. coli* testing for turkey showed a top preference of strategy one, or USDA checks only, at a 10% tolerance level. In fact, the top two ranked preferences were using strategy one. The top ranking tolerance levels were also higher than in the previous sets. The rankings for each group were still identical. The higher tolerance levels and less aggressive strategies could be due to several factors. One, the prevalence of *E. coli* in turkey was lower than in the other meats. Second, like pork, turkey also generates less revenue for a firm than other meats (with the exception of Thanksgiving and Christmas). Finally, at the retail level, turkey is not generally processed as much as the other meats are at retail facilities. Most retail facilities do less alteration to turkey as compared to the other meats. That is, retailer get the product from processors pre-packaged (like frozen whole turkeys) and ready to sell immediately.

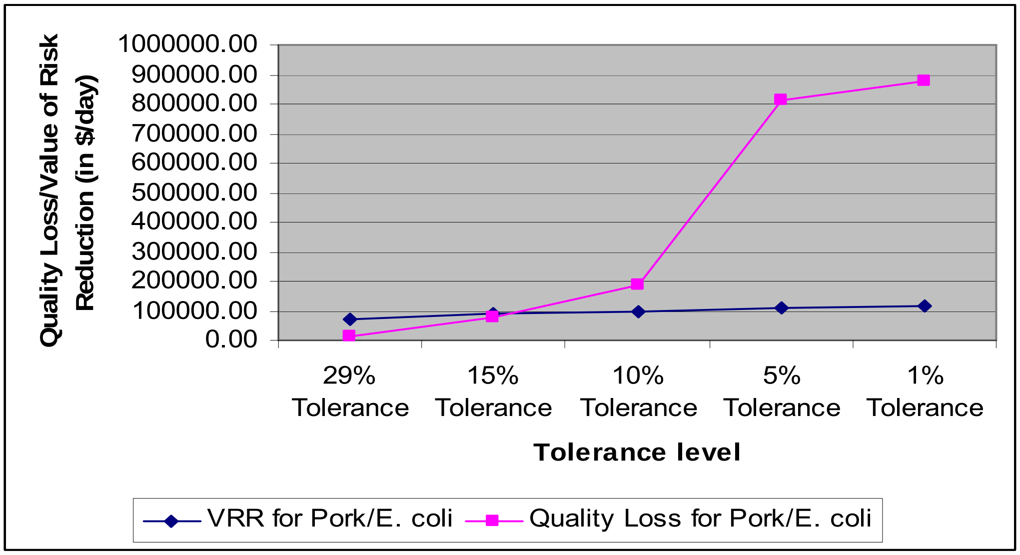


Figure 4.3. Comparison of Quality Loss and the Value of Risk Reduction for Pork with *E. coli* Contamination.

The comparison of quality loss and the value of risk reduction for turkey when concerned with *E. coli* testing are similar to chicken. This is probably because of the fact that they are both considered poultry and both had a lower prevalence of *E. coli*. The 15%, 10%, 5%, and 1% levels all have higher measures of quality loss as compared to the value of risk reduction. The value of risk reduction at the 29% level is just enough to cover the quality loss. However, the preferred strategy for turkey was to test using a 10% tolerance level, while this does not indicate an economic profit, the gap between the value of risk reduction and the quality loss is much smaller. Figure 4.4 is similar to Figure 4.3, in that it suggests that it may not be cost-effective to tighten performance standards below 15%.

Table 4.23 shows the stochastic dominance results for comparing the optimal intervention strategies for turkey products under *Salmonella* testing. Once again all of the preference rankings were identical between the upper and lower RAC. *Salmonella* testing for turkey had a smaller set of optimal strategies because its value of risk reduction was only generated at the 5% and 1% tolerance levels. Thus all of the tolerance levels in the ranking are 5% or lower. The top three preferences use either strategy two or three. The optimal strategy is to use strategy three at a 5% tolerance level.

Table 4.22. Stochastic Dominance Comparison of Intervention Strategies for Turkey Products Under *E. coli* Testing.

Efficient Set Based on SDRF at		Efficient Set Based on SDRF at	
Lower RAC	0.000001	Upper RAC	0.1
Name	Level of Preference	Name	Level of Preference
Strategy 1 @ 10%	Most Preferred	Strategy 1 @ 10%	Most Preferred
Strategy 1 @15%	2nd Most Preferred	Strategy 1 @15%	2nd Most Preferred
Strategy 3 @ 1%	3rd Most Preferred	Strategy 3 @ 1%	3rd Most Preferred
Strategy 2 @ 29%	4th Most Preferred	Strategy 2 @ 29%	4th Most Preferred
Strategy 2 @ 10%	5th Most Preferred	Strategy 2 @ 10%	5th Most Preferred
Strategy 3 @ 10%	5th Most Preferred	Strategy 3 @ 10%	5th Most Preferred
Strategy 3 @ 15%	7th Most Preferred	Strategy 3 @ 15%	7th Most Preferred
Strategy 1 @ 29%	8th Most Preferred	Strategy 1 @ 29%	8th Most Preferred
Strategy 3 @ 29%	9th Most Preferred	Strategy 3 @ 29%	9th Most Preferred
Strategy 2 @ 15%	9th Most Preferred	Strategy 2 @ 15%	9th Most Preferred
Strategy 1 @ 5%	9th Most Preferred	Strategy 1 @ 5%	9th Most Preferred
Strategy 2 @ 5%	9th Most Preferred	Strategy 2 @ 5%	9th Most Preferred
Strategy 3 @ 5%	9th Most Preferred	Strategy 3 @ 5%	9th Most Preferred
Strategy 1 @ 1%	9th Most Preferred	Strategy 1 @ 1%	9th Most Preferred
Strategy 2 @ 1%	9th Most Preferred	Strategy 2 @ 1%	9th Most Preferred

Figure 4.5 shows the comparison of the quality loss and the value of risk reduction for turkey when concerned with *Salmonella* testing. The quality loss and the value of risk

reduction are both zero at the 29%, 15%, and 10% levels because there was no *Salmonella* prevalence in turkey until a 5% tolerance level was reached. Both the 5% and the 1% level show quality loss exceeding the value of risk reduction. Thus, there is no point in testing at those tolerance levels because there would be no premium gained. However, the preferred strategy for turkey was to test using a 5% level and the gap between the quality loss and the value of risk reduction at that level is small. However, the results suggest that tightening performance standard below 10% may not be cost-effective.

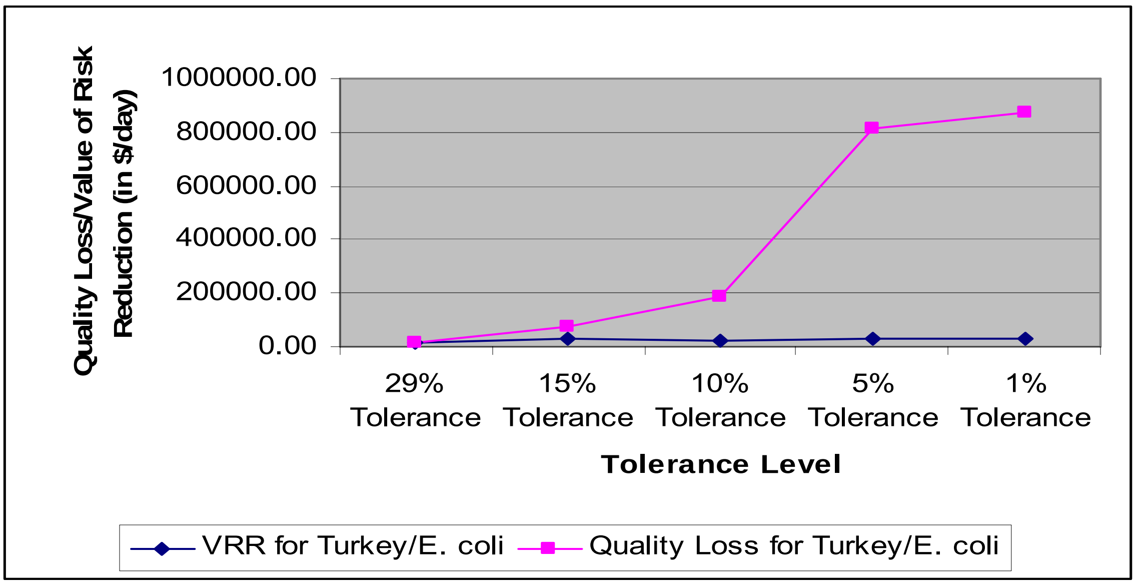


Figure 4.4. Comparison of Quality Loss and the Value of Risk Reduction for Turkey with *E. coli* Contamination.

Table 4.23. Stochastic Dominance Comparison of Intervention Strategies for Turkey Products Under *Salmonella* Testing.

Efficient Set Based on SDRF at		Efficient Set Based on SDRF at	
Lower RAC	0.000001	Upper RAC	0.1
Name	Level of Preference	Name	Level of Preference
Strategy 3 @ 5 %	Most Preferred	Strategy 3 @ 5 %	Most Preferred
Strategy 2 @ 1%	2nd Most Preferred	Strategy 2 @ 1%	2nd Most Preferred
Strategy 3 @ 1%	2nd Most Preferred	Strategy 3 @ 1%	2nd Most Preferred
Strategy 1 @ 5%	4th Most Preferred	Strategy 1 @ 5%	4th Most Preferred
Strategy 2 @ 5%	4th Most Preferred	Strategy 2 @ 5%	4th Most Preferred
Strategy 1 @ 1%	Least Preferred	Strategy 1 @ 1%	Least Preferred

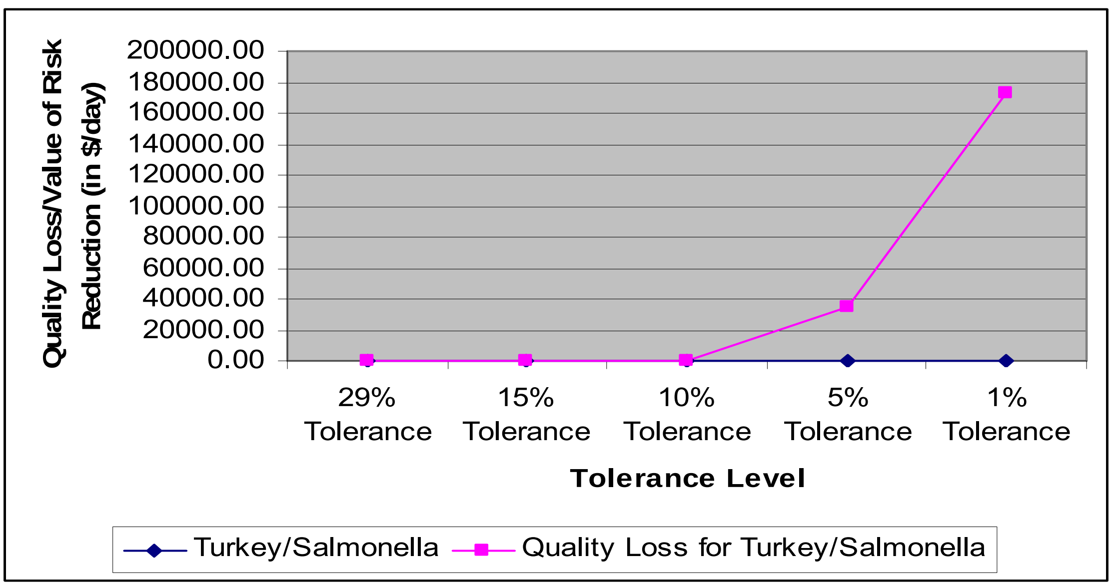


Figure 4.5. Comparison of Quality Loss and the Value of Risk Reduction for Turkey with *Salmonella* Contamination.

Objective 4

Scenario Methods Analysis

The results from the stochastic dominance section are consistent with the hypothesis that voluntary HACCP was a robust intervention strategy for several types of meat. The study then used scenario analysis to determine which factors would be instrumental in the implementation of PR/HACCP at the retail level. Weights were assigned to all the variables (following the procedure outlined in the methodology section), and a report was generated. The variables were given abbreviations. These are shown in Table 4.24.

Table 4.24. Abbreviations for Variables Affecting the Adoption of HACCP at the Retail Level.

Variable	**Abbreviation**
Cost of labor to train employees	LabCos
Cost of restructuring operations	Restruc
Cost of microbial testing	CosMT
Firm's probability of having a foodborne illness outbreak	ProbOut
The number of firms adopting HACCP plans	#adopt
The price of meat products	Price
The demand for meat products	DemMeat
The supply of meat products	SupMeat
The number of foodborne illness outbreak occurring nationally	#OutNation
The public demand for food policy changes	PublicDem
Consumer education about safe food practices	ConsEd
Diet trends in the United States	Diet

Variables that are both strong dependents and have strong influence are the factors that will have the largest impact on the outcome. These variables are shown plotted on a graph; those variables in the upper right-hand quadrant are the strong dependence and strong influence variables. This report showed that the number of foodborne illness outbreaks nationally and the number of retail firms leading the adoption of PR/HACCP plans were the two variables that were most likely to have a direct influence and dependence on the implementation of mandatory PR/HACCP regulations (Figure 4.6). A direct influence and dependence means that these factors are directly impacting the outcome.

There were four variables that had indirect influence and dependence on mandatory HACCP regulation (Figure 4.7); these variables were the number of foodborne illness outbreaks nationally, the number of retail firms adopting HACCP plans, the public demand for change in food safety policy, and the probability of a foodborne illness outbreak for an individual firm. Indirect dependence and influence means that these variables do not appear to have an impact on the outcome itself, but rather, they affect other factors that will ultimately impact the outcome. These results show that the probability of an outbreak is an important variable. The more outbreaks that occur, the higher the likelihood of mandatory HACCP occurring. Surprisingly, costs were less important in the outcome than pilot or leader firms that were adopting PR/HACCP. Not surprisingly, outbreaks occurring, either at the firm itself or nationally, both had impacts on mandatory PR/HACCP regulation.

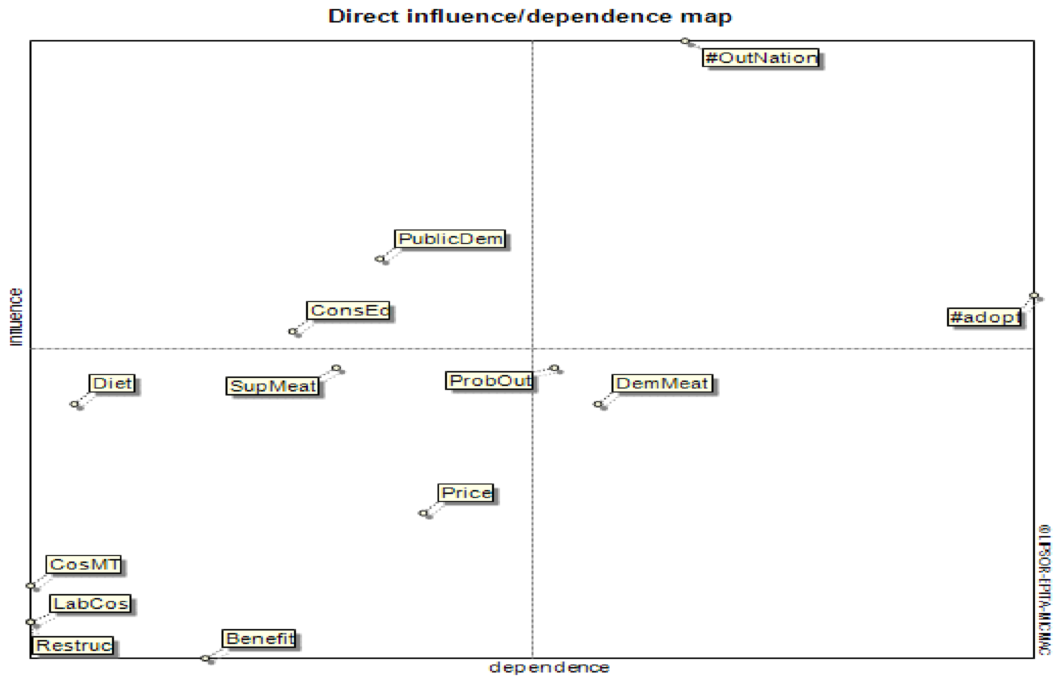
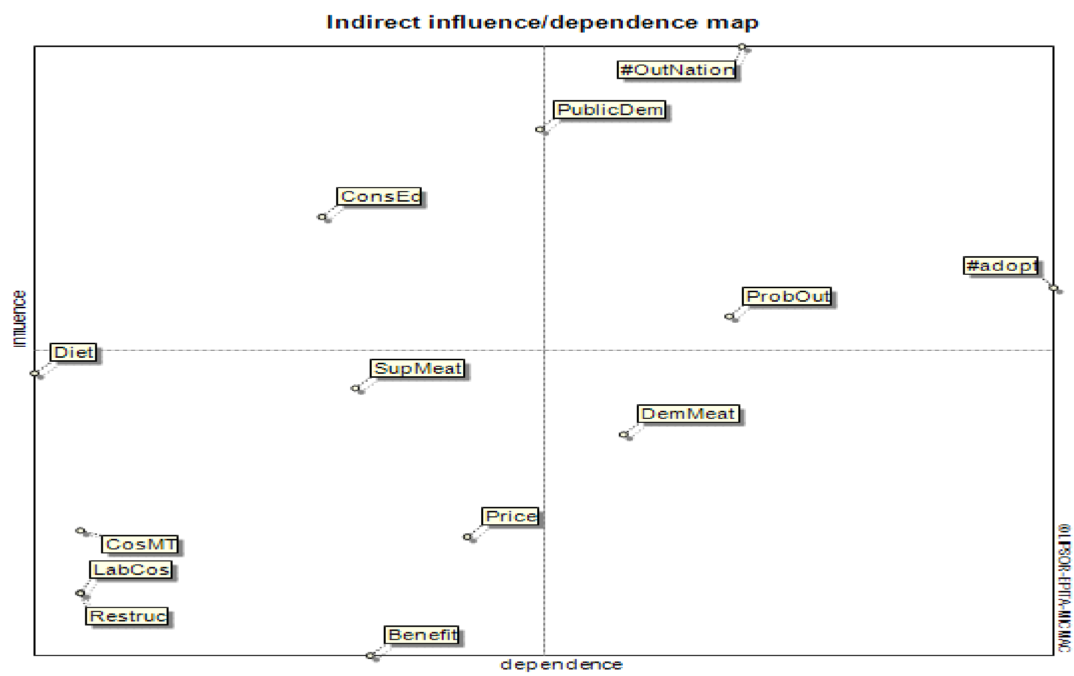


Figure 4.6. Direct Influence/Dependence Map for Retail PR/HACCP Implementation.



CHAPTER 5. CONCLUSIONS AND IMPLICATIONS

Summary of Introduction

Food safety has been the subject of extensive research on aspects of social costs and firm level costs. PR/HACCP implementation has been of particular interest in the past decade. The debate has primarily focused on whether the benefits of PR/HACCP programs outweigh the costs and whether it is effective in reducing food safety risks. PR/HACCP was initially applied to the processing sector in the United States as a way to "fix" the problem of repeated foodborne illness outbreaks in the late 1980's and early 1990's.

Mandatory PR/HACCP has been in effect for the processing sector for ten years. According to the CDC, pathogen levels have decreased significantly since 1996, but outbreaks of foodborne illness are still quite significant. This raises lots of questions. About 50% of all foodborne illness outbreaks that occur at the retail sector are traced to restaurants and delis. This suggests a need for intervention at the retail level.

Summary of Objectives

The main objective of this study was to determine an optimal food safety intervention strategy that incorporates risk, cost, and the value of pathogen reduction. In other words, to determine optimal testing and sampling within each strategy. To achieve this objective, a stochastic optimization model was used to maximize an expo-power utility function of the net benefit of different intervention strategies and different risk preferences. From those optimal strategies the goal was to determine the value of risk reduction and quality loss that was associated with each strategy. The value of risk reduction is the risk premium or compensation for implementing alternative risk mitigation strategies. Quality loss was determined using the Taguchi Loss function. Given there are three strategies to use at the retail level, the next objective was to compare the alternative strategies to determine what strategy was most cost-effective among the three. This was accomplished by using stochastic dominance to rank the optimal strategies. The last objective of the study was to use scenario methods to determine what factors affect the adoption of a mandatory PR/HACCP regulation by the government.

Summary of Methods

Stochastic optimization has been especially helpful when trying to measure firm level costs and risks under conditions of uncertainty. This model, which was adopted from Nganje, Kaitibie, and Sorin (2005), was extended into the retail level, and it was useful in analyzing the costs and benefits of PR/HACCP implementation at the retail level. The main advantage of stochastic optimization is that it is capable of assigning distributions to variables that are random. This was beneficial when determining profits, quality loss, and the value of risk reduction as well as for simulating labor and testing costs. It also can be used to fit distributions to a data set that has been collected. This was helpful when simulating contamination data and assigning distributions. Stochastic dominance allowed for ranking of the optimal strategies found by using stochastic optimization. The value of risk reduction estimates were used to make this comparison. Risk aversion coefficients were used to analyze the rankings under extreme risk aversion and risk neutrality. These rankings were used to confirm our hypothesis. Finally, scenario methods played a role in analyzing factors that would affect the adoption of mandatory PR/HACCP regulation. This method gives a more clear idea of factors that can influence the future prospect of mandatory PR/HACCP.

Summary of Results

From this analysis, probabilities of *E. coli* contamination were high across all meat types. Some pathogens were not present in certain meat types. For instance, in our data set the prevalence of *Salmonella* contamination in beef or pork was nil. This might explain why retail facilities adopt alternative risk mitigation strategies. Those that process beef into sausages may be more prone to implement voluntary PR/HACCP to minimize *E. coli* prevalence. Quality loss and risk reduction values are higher when there is a higher probability of contamination. Risk reduction values increased as tolerance levels were tightened and quality loss estimates increased as tolerance levels were tightened. These results also show that retailer will incur higher quality loss costs if there is no mitigation strategy implemented to reduce contamination and also if there are stricter performance standards.

Optimal intervention strategies varied by meat type and pathogen type. Beef especially showed a need for *E. coli* testing at the retail level. This might suggest a need for testing for *E. coli* at the processing level. *Salmonella* is currently the only performance standard because of the assumption that when *Salmonella* level decreases other pathogen levels will also decrease. Our study suggests that this might not be entirely true. It appears that when *Salmonella* levels decrease, levels of other pathogens do not necessarily decrease with them or do not decrease enough to ensure a safe product.

Chicken and pork also showed a need for *E. coli* testing at the retail level. While the probability of contamination for chicken and pork was not as high as beef, it was still significant to be tested. Turkey should also be tested for *E. coli* but not as intensively as the other meats. This could be because of the lower *E. coli* contamination levels in turkey and also because retail meat shops handle turkey (e.g. grinding or repackaging) less than the other meats. This can also decrease the likelihood of cross contamination.

Beef and pork showed no *Salmonella* contamination and no testing was required. For chicken, the optimal testing strategy is at a 1% tolerance level. Turkey showed a need for *Salmonella* testing but at a tolerance level of 5% and 1%.

Testing for *Campylobacter* was similar to *Salmonella* testing in the fact that it was only suggested to test for it at the lowest tolerance level of 1%. Testing was only recommended for beef and turkey under DARA and for only pork under CARA. Chicken showed the highest prevalence of *Campylobacter* as compared to the other meat types. This could also be due to the fact that chicken is not handled as much as beef or pork, so there is a smaller likelihood for pathogen growth or contamination and cross contamination.

The stochastic dominance analysis showed that the most preferred testing strategies was at tolerance levels lower than 5%. This suggests a need for tightening tolerance levels. However, graphical analysis of quality loss and the value of risk reduction suggest tolerance levels could only be tightened to 15% or 10% prevalence levels. Strategies 2 and 3, or hiring a private firm and voluntary HACCP, respectively, showed up often in the top rankings of the stochastic dominance analysis. In the case of beef possibly being contaminated with *E. coli* and the case of chicken possibly being contaminated with *E. coli*, strategy 3 was the preferred strategy. Strategy three was also preferred for *Salmonella* testing in turkey products. Strategy 2 was ideal for pork when testing for *E. coli* and strategy 1 (USDA testing only) was only optimal for testing for *E. coli* in turkey. This suggests a need for PR/HACCP at the retail level.

The use of Micmac software enabled a look into what factors might serve as incentives to facilitate PR/HACCP at the retail level. Two strong driver, and dependent variables were identified, the occurrence of outbreaks and the number of other firms in the industry that would voluntarily adopt PR/HACCP plans. This means that any push towards large-scale adoption of PR/HACCP policy will come from within the retail meat industry itself, either through a realization of needing to reduce the number of outbreaks or through a need to compete with other firms to keep up with changes in the industry.

Implications for Firms

This study can motivate firms to begin looking at adopting PR/HACCP plans for their restaurant facilities. Of the outbreaks that were occurring at the retail level, 50% of those were happening in restaurants and delis. This could suggest a need for better risk mitigation strategies in those firms. Retail meat shops tend to have better practices than restaurants because the retail meat shops specialize specifically in meat, thus they are handling fewer products. Restaurants and delis deal with a wide variety of potentially hazardous foods; they do not specialize in one or two types of food. Workers in those restaurants and delis have a lot more safe handling practices to remember and they also need to be more cautious about cross contamination. This could also motivate the adoption of voluntary PR/HACCP among these types of firms.

Another opportunity for these firms could be food recall insurance. Food recall insurance is not only a way for firms to manage their risk, but also gives incentive for firms to find, continue practicing, and evaluate their optimal mitigation strategies. A firm would be motivated to adopt a HACCP or HACCP-like program in order to qualify for food recall insurance. The impact of adoption of HACCP plans to obtain food recall insurance could change the role of government intervention in food safety (Skees, Botts, Zeuli, 2001). A program for food recall insurance could help reduce the need for government intervention in the market for safe food. It could also motivate earlier recalls and help reduce the number of foodborne illness outbreaks.

However, asymmetrical information is present in the insurance market as well. The firms know more about their food safety practices than insurance companies do. This asymmetrical information in the insurance market may lead to adverse selection. Adverse selection means that the food recall insurance policies would attract the firms that need protection the most (i.e. those engaging in unsafe practices). Moral hazard or offsetting behavior could be another concern (Hause, 2006). Plants could possibly relax their food safety standards because they know they are protected by food recall insurance.

Implications for Policymakers

This study suggests a need for extending the PR/HACCP performance standard to retail facilities and other pathogens. Currently, *Salmonella* is the only performance standard for HACCP. The assumption is that if *Salmonella* levels are decreasing then so are other levels of pathogens. However, this does not appear to be the case (table 4.1). The data set used showed a high level of *E. coli* contamination across all meat types. This could be one of the reasons we are still seeing a large number of outbreaks (especially *E. coli* outbreaks), even though pathogen levels have decreased significantly in the last decade. This could signify a need for other pathogen tests and not just *Salmonella*.

This could also suggest a need for tightening of tolerance levels. Perhaps, the need is not for different types of pathogen testing, but for more intense testing. A tightening of the tolerance level to a level lower than 29% could possibly fix some of the problems with high levels of pathogens as well. However, the study done by Nganje, Kaitibie, and Sorin (2005) suggested that tolerance levels at the processing sector could be tightened, but not below 15%. The results in this study suggest that when concerned with *E. coli* contamination, tolerance could not be tightened past 29% for chicken and turkey, and tightened only to about 15% for beef and pork. Tolerance levels when testing for *Salmonella* in turkey could be tightened to 10%. This was because of high quality loss as compared to the value of risk reduction when tightening occurred.

At the retail level, this study can encourage policymakers to take steps toward encouraging a movement to PR/HACCP or contract inspection, such as providing incentives to firms that are adopting plans and taking initiative to ensure a safe food supply. Even though HACCP has been proven to be cost-effective at the processing level, there are still concerns. Moral Hazard problems can arise if firms are not using appropriate record-keeping practices. This can happen if a firm is not carefully tracking temperatures or sanitization processes or forgetting to record number and then just fill out the records later is a 'best guess', but do not know the exact number for sure. This creates moral hazard because the USDA and the FSIS would be under the impression that the firm is doing everything they can to prevent a foodborne illness outbreak, but really they are not following the procedure precisely and thus there is a breakdown in the market for safe food. Before policymakers implement HACCP at the retail level, they need to address these challenges. The fact that HACCP is mandatory at the processing level provides them with a good tool. They can look back at the processing level to determine what the challenges might be for the retail level. This would make the transition into retail HACCP much smoother.

The results of the scenario analysis suggested that an increasing number of outbreaks occurring nationally could have a large impact, directly and indirectly, on mandating PR/HACCP in retail facilities. CDC data from the introduction section, showed that even though pathogen levels have been decreasing since 1996, the number of foodborne illness outbreaks have been increasing. This could possibly mean that the United States is on the verge of a change from its current food safety policy to a policy of mandatory PR/HACCP in retail facilities. If this is the case, policymakers need to pay close attention to studies on PR/HACCP benefits and cost so that they can formulate a policy that helps retail facilities make a smooth transition from their current practices to a PR/HACCP plan.

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